PHYSICAL PROPERTIES OF WESTERN SUDAN WATERMELON (*Citrullus vulgaris*) AND WATERMELON SEEDS

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Dedication

To my dear Family
Father (God Bless his Soul)
Mother
Sisters and Brothers

There are no words adequate enough to express my feeling

Nuha

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List of Abbreviations

Abbreviation	Meaning
AOAC	Association of Official Agricultural Chemists
AOAD	Arab Organization Agriculture Development
FOA	Food and Agriculture Organization of the United Nation
ISNAR	International Services and National Agricultural Research
UNICEF	United Nations International Children's Emergency Fund
WFP	World Food Programme

Abstract

This study was conducted to determine the physical properties of Western Sudan watermelon (*Citrullus vulgaris*) and watermelon seeds to be used in the design of a machine to harvest and separate watermelon seeds from the pulp.

The samples were selected from the 2003/04 and 2004/05 growing seasons. The actual volume of watermelon was determined by water displacement method and then the watermelon density and specific gravity were determined. The three axial diameters were measured using an overhead projector. The relationship between the actual volume and the measured dimensions was determined to verify that the estimated volume may be used as a criterion to decide that if these dimensions were sufficient to define watermelon form. The shape of Western Sudan watermelon was resembled by sphere, oblate spheroid and prolate spheroid. The predicted watermelon volumes using the three geometric shapes models were related to the actual volumes. The actual watermelon surface area was determined using a digital planimeter then the rind thickness was measured using a vernier caliper. The predicted surface areas using the three geometric shapes were related to the actual surface areas. The actual watermelon surface area was related to its weight and volume by assuming a linear and non-linear regression models. The predicted surface areas using these two models were related to the actual surface areas.

The initial moisture content of watermelon seeds was determined using an air oven method. Then the specific gravity of watermelon seeds was determined using the method of pycnometer and toluene. The weight of 100 seeds, the percentage of red and brown seeds and the percentage of large seeds were recorded to be used in grading the watermelon seeds. The oil content of each watermelon seed variety was found using a soxhelt extracting apparatus.

The results showed that both the watermelon density and specific gravity were 0.876 g/cc and 0.892, respectively. The estimated watermelon volume can be used as adequate criterion then the measurement of three axial dimensions, gave a complete theoretical specification of the watermelon shape and size. The oblate spheroid model was found to be more accurate in predicting the volume and surface area of Western Sudan watermelon compared to the sphere and the prolate spheroid models. This suggested that the watermelon shape can be described by an oblate spheroid. The average rind thickness of watermelon was 0.37 mm. Linear regression models were developed to correlate the watermelon surface area with both its weight and volume. It was found that there was strong correlation between the watermelon surface area and its volume than with its weight. Also it was found that the oblate spheroid model was the most accurate predictor of the watermelon surface area among the models tested. The average initial moisture content of the watermelon seeds dried at 105±1°C for 48 hrs was 38.2% (moisture, w. b.). Based on this moisture content, the average specific gravity of the watermelon seeds was 1.016. The watermelon seeds involved in this study were graded as Super Casheir, Casheir, Normal White and Farrasha – third. The watermelon seeds yield a valuable amount of oil ranged from 20.05 to 24.05%.

Key Words: Western Sudan watermelon; physical properties; criterion.

ملخص الأطروحة

عنيت هذه الدراسة بإيجاد الخصائص الفيزيائية للبطيخ البلدي (*Citrullus vulgaris*) المزروع بغرب السودان والخصائص الفيزيائية لحب البطيخ لتستخدم في تصميم آلة لفرز الحب من لب البطيخ.

تم إجراء التجارب على عينات أختيرت عشوائياً من إنتاج موسمي 2003/04 و2004/05. تم إيجاد الحجم لكل عينة بإزاحة الماء ومن ثم أستخدم لحساب الكثافة والثقل النوعي. أستخدمت طريقة الإسقاط الضوئي لتحديد وقياس الثلاثة أبعاد المتعامدة لكل عينة ليعرف بها المقاس كما أستخدم الحجم كمعيار لتحديد ما إذا كانت هذه الأبعاد كافية لتعريف الشكل و المقاس. قُرب شكل البطيخ بثلاثة أشكال، الكروي (sphere)، والكروي المفلطح (oblate spheroid)، والكروي المدبب (prolate spheroid) ومن ثم تم تقدير الحجم الذي قُورن بالحجم الحقيقي لتحديد شكل البطيخ. أيضاً تم تقدير مساحة السطح بنفس الطريقة وقُورنت بمساحة السطح الحقيقية التي قيست بالاستشفاف بواسطة الممساح (digital planimeter) و بعد ذلك تم قياس سمك القشرة (Rind). ربطِت مساحة السطح للبطيخ بكل من الوزن والحجم بمعادلات تجريبية استخدم فيها الارتداد الخطي (linear regression) واللاخطي (non-linear regression) كما قُدِرت مساحة السطح من هذه المعادلات وقُورنت بمساحة السطح الحقيقية.

جفِف حب البطيخ الناضج المستخرج من لب البطيخ بالفرن عند درجة حرارة 105±1°C لمدة 48 ساعة لإيجاد المحتوى الرطوبي الابتدائي لحب البطيخ (initial moisture content) ومن بعد ذلك أستخدمت زجاجة الثقل النوعي (pycnometer) مع التولوين ($C_6H_5CH_3$) لإيجاد الثقل النوعي لحب البطيخ. تم تدريج حب البطيخ حسب صفاته الفيزيائية (وزن المائة حبة، نسبة الحبوب الحمراء والبنية ونسبة الحبوب الكبيرة) إلى مجموعات. أُستخِلص الزيت من كل مجموعة بواسطة (Soxhelt Extractor).

أشارت النتائج إلى أن متوسط كل من الكثافة و الثقل النوعى للبطيخ هو 0.876 g/cc و 0.892 على التوالي. أن قياس الثلاثة أبعاد المتعامدة يعرف الشكل تماماً، استنادا على أن تقدير الحجم باستخدام هذه الأبعاد يعطي نتائج دقيقة. تبين الدراسة أن تقريب الحجم ومساحة السطح باستخدام معادلات الشكل الكروي المفلطح (oblate spheroid) يعطي نتائج أفضل من الـ(sphere) والـ(prolate spheroid) وعليه يمكن وصف البطيخ البلدي بأنه كروي مفلطح. وجد أن متوسط سمك قشرة البطيخ هو0.37 mm .تبين الدراسة أن العلاقة الخطية

بين مساحة السطح الحقيقية وكل من حجم ووزن البطيخ يعطي نتائج جيدة إلا أن علاقة الحجم أقوى من الوزن وتمضي الدراسة في أن المساحة المقدرة باستخدام معادلة الشكل الكروي المفلطح أدق من بين كل الطرق المستخدمة رغم بساطتها.

أظهرت نتائج الدراسة أن متوسط نسبة الرطوبة الابتدائية في حب البطيخ هو 38.2% (أساس رطب)، و عند هذا المحتوى الرطوبي وجد أن متوسط الثقل النوعي لحب البطيخ هو 1.016 و أن نسبة الزيت فيه تتراوح بين 20.05-24.05%

CHAPTER ONE

INTRODUCTION

The Western savanna region, which administratively embraces Kordofan and Darfur states, covers a total surface area of 850,000 km^2 which account to about 34% of the whole country. The ecology of this region is mainly determined by the total annual rainfall. Except for the southern area, this region is typically in the low rainfall savanna belt. The agriculture depends on rainfall. The traditional rainfed farming, widely practiced in the area fluctuates from year to another, according to the availability of farming inputs and amount of the rainfall. Rainfall occurs in successive three months, from July to early October comprising the wet season, which is suitable for the growth of major and minor crops such as Sorghum, Millet, Sesame, Gum Arabic, Groundnuts, Karkadeh and Watermelon. The rainy season is followed by a dry period of approximately nine months. During the dry season watermelons grown in Western Sudan may remain fresh until the start of the next rainy season, constituting a perennial source of water for human and animals. Watermelon seeds represent a multi-purpose crop, they are consumed in the rural areas in the form of various food stuffs and in the form of fried seeds sold as a cash crop all over the Sudan, Egypt and other near countries. There are many different varieties of Western Sudan watermelon seeds, but the white variety is the most preferable in trading. Animals consume watermelon seeds in the form of feed stuff in poultry ration.

For industrial consumption, oil from watermelon seed is mainly used as cooking oil in the Sudan. It is hoped that some alternative uses of watermelon seed will be revealed which will contribute positively to the improvement of diets in West of Sudan and that the poor farmers will find new ways to benefit from this indigenous crop. For small scale production, the seeds are separated manually, but for commercial production there is a need for designing and testing a machine to harvest and separate watermelon seeds. In order to be able to carry out such investigation, the physical properties of watermelon and its seeds are needed. Such information was not found in the literature reviewed and, there is a need to conduct research in this regard.

Thus the objectives of this research are as follows:

1. To determine the physical properties such as size, shape, volume, density, specific gravity, surface area and rind thickness of Western Sudan water melon.
2. To develop a relationship between watermelon surface area and both its weight and volume.
3. To determine some properties of watermelon seeds such as initial moisture content, specific gravity and oil content.

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4. To determine the physical properties such as size, shape, volume, density, specific gravity, surface area and rind thickness of Western Sudan water melon.
5. To develop a relationship between watermelon surface area and both its weight and volume.
6. To determine some properties of watermelon seeds such as initial moisture content, specific gravity and oil content.

CHAPTER TWO

LITERATURE REVIEW

2.1 Watermelon:

2.1.1 Origin:

Watermelons have been cultivated since prehistoric time, they were grown by the ancient Egyptian, and apparently cultivated thousands of years ago in Asia Minor, Russia, and the Near and Middle East (Pierce, 1987).

The plant was thought to be originally coming from Africa, particularly native to Central Africa, although explorers reported evidence of possible American origin. Descriptions indicated that the early American melon was of the Citron type (Ware, 1968).

Early French explorers found Indians growing watermelon in the Mississippi Valley. Its culture was not known in Europe until the sixteen century (Ware, 1968).

In term of world production watermelon is currently grown mainly in China, Turkey, the USSR, Egypt, the USA, Iran, Japan, Italy, Spain and Syria (Snowdon, 1990, Robinson and Decker, 1999).

Gokovsky (1971) reported that Sudan is considered as the centre of origin of watermelon especially Kordofan Zone, where it grows as a wild plant. Also watermelon grown in sandy soils and clay and gardud soils in Darfur state on commercial basis (Abaker, 1990). Beside the Western Region, watermelon is grown in loamy or clay soils of the Gezira near the White Nile, Atbara, the River Nile and Elgash and Toker.

2.1.2 Classification:

The cucurbits (family cucurbitaceae) form a diverse group of species grown around the world under many conditions and for many different purposes.All cucurbits are frost sensitive, but they differ in their ability to withstand cold and heat. They are grown in low lands and mountains, in fields, green houses, in tropical desert and temperature regions. The major cultivated types include cucumber, melon (cantaloupe or musk melon, honey dew, etc.), squash (cucurbita spp.), pumpkin, and watermelon. Despite the large differences between and within the cucurbit species, they are morphologically very similar in appearance. The germination of cucurbit vegetable seeds requires relatively warm temperature (Lorenz and Maynard, 1980), and takes place within 3 or 4 days at 25-30°C. Cucurbit seeds will continue to develop even after the fruit is removed from the vine. If fruits are harvested before they are fully mature, due to impending frost or other reasons, it is advisable to store them 1 or 2 months before extracting the seeds.

For commercial seed harvesting, special machinery were used. Recent inventions include the seed sluice for small plots, the bulk seed extractor and the single fruit seed extractor, which is used in the glass house or laboratory to extract cucumber seeds (Wehne and Humphries, 1995).

Removing the persistent placental material encasing cucumber and bitter melon seeds is aided by fermentation. The water and seed mixture are allowed to set for (1-2) days, depending on the temperature (20-30°C). Fermentation is complete when seeds settle to the bottom of the container and the placental material floats. The seeds are then rinsed and set out to dry. Embedded seeds of watermelon can be removed by chopping and smashing the fruits and adding water to the mixture, seed will sink and the flesh debris, which floats, is poured off.

A dilute solution of hydrochloric acid or ammonia can be used to clean cucumber seeds more quickely. After vigorous stirring, the seeds are free of flesh in 30 min or less. They must be rinsed before drying.This or any other mechanical means of seed cleaning should not be used with a bitter melon seeds which are easily broken (Robinson and Decker, 1999).

Where sun drying is possible, seed may be spread in screen-bottom trays placed on racks under warm (<35°C), arid conditions. Artificial drying is also practiced with various bin-type driers and revolving drum units. Indirect heated air is forced down the tunnel and up through the seed-filled trays.

Usual recommondations suggested a 100°C as the maximum safe temperature when the cucumber seed is wet and 110°C as the seed become drier (year book of agriculture, 1961). Commercial producers use forced air warmed by propane heaters and flat drying beds or large rotary dryers to dry the seed to moisture content of 5-8%. Under these conditions, cucurbit seed may remain viable for as many as 10 years or more (Whitaker and Davis, 1962, Robinson and Decker, 1999).

Three species of *citrullus* are generally recognized: *Citrullus lanatus*, *Citrullus ecirrhocogn* and *Citrullus Colocynthis*.

Within *Citrullus lanatus* domesticated watermelon belongs to *var. lanat* where as wild populations are generally classified as var. *Citroidies* (Baiely) Mansf. (Navot and Zamir, 1987).

2.1.3 Botanical Features:

Watermelon is an aggressive vining annual plant adapted to mean temperatures greater than 21°C.

Watermelon differs from other economically cucurbits by having pinnatifid leaves, with 3-4 pairs of lobes which are subdivided and toothed. The hairy stems are growing up to 5 m, they are thin, angular and grooved with 2-3 branched tendrils. Dwarf watermelon varieties with reduced internode have been bred, but most commercial cultivators are highly branched vines, measuring up to 10-m in length (pierce, 1987, Robinson and Decker, 1999).

The root system is deep, extensive and superficial (Pierce, 1987), whereas Robinson and Decker (1999) reported that the root system is relatively extensive but shallow. Petiols are 1-10 cm in length. The flowers are 2-3 cm in diameter with 3-5 stamens and hairy ovary (Rice, *et. al.*, 1987).Watermelon is monoecious. The solitary, light yellow flowers are less showy than those of many other cucurbits.

The rind varies from white to green and may be stripped or mottled (Rice, *et. al.*, 1987). It can be thick or thin, the 1-4 cm. Thick rind is hard but not durable. The flesh at maturity can be white, yellow, orange pink or red (Sonowdon, 1990 and Robinson and Decker, 1999).

In addition to sweet there are bitter types. Among the latter there is a form of *citrullus lanatus* known as "Egusi", grown in some regions of Nigeria, whose flesh is inedible and only the seed are used (Rice, *et. al.*, 1987).

Watermelon fruit pulp includes numerous flattened seeds constituting about 1.9-4.0% of fruit flesh (Kamel, *et. al.*, 1985). Seeds differ in color; they may be black, brown, red, yellow and rarely white (Oyolu, 1979). They differ in size, thickness, texture of the seed coat and the thickness of seed edges which maybe flat or moulded. Basically there are small, moderate and large size seeds. It has been reported that they are about

0.6-1.5 cm long and 0.5-0.7 cm wide. Usually about 15 seed/g are found and their presence throughout the flesh makes removal difficult (Hussein, 1998).

2.1.4 Importance and Uses

It is generally recognized that vegetables are considered as an important food group and will contribute positively to the improvement of diets in the developing countries. They are rich source of essential vitamins, minerals and dietary fiber and provide addition calories. The average nutritive value of watermelon is summarized in Table (2.1).

Table (2.1): Average nutritive value of watermelon per 100 gms edible portion:

Crop	Moisture % age	Vitamin A (μgRE)	Vitamin C (mg m)	Protein (gm)	Iron (mg)	Calcium (mg)
Watermelon	93	150	7	0.5	0.4	14

Source: Report to the minister of Agriculture and Natural Resources on the integrated vegetable crop in the Sudan, 1993.

Watermelon originated in Africa is fat – free and low in Sodium, have high water content and low caloric value, it is a good source of vitamin A (Whitaker and Davis, 1962).

Watermelon is used mainly as a dessert, but the Western Sudan watermelon, due to the problem of water shortage variety represents a perennial source of water for man and animals due to the problem of water shortage. In some rural areas, for instance, El Nuhood rural council, the whole farmer’s income generated from farming activity will be spent in purchasing and transporting drinking water (Adam, 1999). Instead of water, rural families use the juice of water melon to prepare tea, which is known as “El Zenkalait”.

The suitability of Kordofan watermelon for jam manufacture is well known. It gives a nice jam, with less off flavor noted in dessert watermelon.

Young leaves and young fruits are cooked as vegetable added to soups, or used as a relish.Unripe fruits are boiled and mixed with groundnut and eaten as a salad known as "Sabalay".

As folk medicine fruits are eaten in large quantities to aid extraction of kidneys stones, for treatment of gonorrhea and female discharges. Fruits of bitter form of watermelon are used as purgatives. For animal feed the fruit rind and the green parts of the plant are used for livestock feeding (Hussein, 1998).

Watermelon seeds protein isolate has great potential for incorporation into human food products not only as a protein supplement in diets of under nourished but as functional agent in different food products. It exhibits some good functional properties. The protein solubility must be raised above the minimum value by pH variation or salt addition in order to incorporate it in liquid foods, has good emulsifying and foaming properties that allow its use in whipped toppings, chiffon deserts and cakes. Water retention of watermelon seed protein allows its use in breads and cakes and infants and weaning foods, can be incorporated in meats, curds, and chase due to its good gelation (Hassan, 1994). Defatted meat may be suitable for incorporation into diabetic food (Sharma, *et. al.*, 1995).Watermelon seeds contained nutritionally useful quantities of essential amino acids as well as minerals which made them potentially useful as food supplement (Zhang, *et. al.,* 1990 and Olaofe, *et. al.*, 1994).In determining minerals in watermelon kernel, it was found that Potassium (K) was the predominant mineral and Calcium (Ca), Magnesium (Mg), Sodium (Na), Manganese (Mn), Iron (Fe) and Copper (Cu) in moderate high amounts (Olaofe, *et. al.*, 1994). Previous and recent results showed that watermelon seed would indeed constitute a valuable source of the major elements of Iron (Fe), Zink (Zn), Manganese (Mn), and Cobalt (Co), particularly in diet of the humans, since no special provision is made for the supply of these vital nutrients. Table (2.2) gives the constituents of the total ash for the watermelon seed kernel which were determined by Hassan (1998).

Table (2.2): Watermelon seed minerals:

Mineral	mg/Kg	Mineral	mg/kg
Calcium (Ca)	0.68	Na	10.5
Manganese (Mn)	0.14	K	53
Cobalt (Co)	0.03	Mg	28
Copper (Cu)	0.86	Zn	0.94
Iron (Fe)	1.87		

In Africa where the plant is called “Egusi” although has bitter, white flesh, the non bitter seeds are roasted and eaten.

79% of the total production of watermelon seeds in Western Sudan is consumed locally, where 63% goes to direct human consumption, in the form of fried seeds and in the form of various food stuffs (Rainfed, Agric. Development Strategy, 1985). “Bajbajei” is a local pudding, made by cooking finely ground raw watermelon seeds in boiling milk, served hot to all member of the family (Saied, 2002).Also the farmers use the mixture of watermelon seed and grains to prepare “Aseeda” and local bread.

In Cameroon, watermelon seeds are ground in to a paste and added to cassava leaves and cooked into a sauce (Guanfobe, *et. al.*, 1991). Decorticated ground watermelon seeds are used as a flavor component of gravies (Nwokolo, 1987).

In Nigeria watermelon (Citrullus Colocynthis) seeds are processed and cooked in a variety of forms depending on traditional practices and taste preference. The seeds are usually dehulled and/or subjected to grinding, toasting, fermentation or germination, depending on the type of food and the region of consumption. The undefatted melon kernel meal is an important condiment in traditional soups and stews, in which it acts as thickening and emulsifying agent. Partially defatted meal is also an important condiment in traditional soups and stews, in which it acts as thickening and emulsifying agent. Partially defatted meal is also dry roasted and consumed as snak or fermented traditionally to produce Ogiri, a flavoring agent for use as soup condiment (Oyolu, 1977, Nwokolo and Stim, 1987, Akubor, *et. al*., 1982, Giami and Bekabi, *et. al*., 1992, Akubor, 1988, Offonry and Achi, 1998, Akubor, *e,. al*., 2002).

It was found that the traditional processing methods employed for the preparation of melon seeds to human food products affect the nutrients, functional properties and treatments. Toasting and fermentation improved the protein content of melon seed but germination decreased it. Similarly germination, toasting and fermentation decreased the crude fat content.

While germination and toasting improved the crude fiber, fermentation failed to do the same. The various capacity test showed toasted, germinated and fermented melon kernel flours to possess functional properties that lend them to various food application. However, further studies are necessary to evaluate the effects of such treated melon kernel flours on the quality of formulated foods (Akubor, 2002).Also Saied (2002) concluded that roasting of watermelon seeds led to an improvement in the apparent retention of crude protein.

Watermelon seeds are combined with sesame to produce oil cakes for cattle, watermelon seeds are fed directly to poultry (mainly pigeon and chicken). Watermelon seeds are also fed directly to goats and sheep at times of shortage of pastures (Rainfed Agric. Development Strategy, 1985).Saied (2002) and Hussein (1998) concluded that whole ground watermelon seeds can be included at 10% and 15% (w/w) at the expense of groundnuts cake in broiler rations without adversely affecting growth performance or eating quality of meat. However, the economic aspects of inclusion of this unconventional feed ingredient are yet to be investigated.

Watermelon seeds can be used as medicine. It was found that watermelon seeds oil eliminates the reason of formation of stones in kidneys, preventing development of irreversible changes in kidneys, dissolves and washes away slime, salutarily influences removal of inflammatory processes in urogenital system and normalization of acid-base balance, promotes transition of auric acid from fabrics in blood and strengthens removing it by kidneys, prevents formation of new stones. As well as in pumpkin oil, the optimum contents of Zinc and Selenium normalizes activity of prostate gland, interfering with an inflammation prostaty (prostatistis), influences a normal sexual condition of an organism, improving spermatogenez, promotes fast healing of grazes, wounds, burns, acceleration of growth and restoration of a healthy kind of, hair, nails, muscles. In a combination to high concentration oleinovoj acids stimulates manufacture prostoglandinov, thus improving a metabolism and reducing of acne agminata, reduces probability of diseases by a cancer and reduces practically to zero risk of prostatic adenoma. The recommendations for application are as follows:

- At chronic defeat of kidneys and stones in Pelvis – on 1-2 tsp. 3-4 times per day 0.5-1 hour prior to meal. Cure: 300-500 ml duration 2-4 months.

- Acne agminata – to grease the cleared skin 2 times per day. Inside on 0.5 tsp. 4-6 once a day. The common cure: 250-800 ml. Duration of 3-6 months.

- Blandness – to rub in a skin. Once a week nutritious mask. Shampoo on the basis of oil. Inside on 1-2 tsp. per day.

- Preventive from hepatities, prostatitis, tumours (including adenomas), Cancer, early baldness, diseases of the digestive tract and kidneys, uorlithasis and cholelithlasis. A cure: 500 ml. one tsp. every day during one year.

- As food-oil is compatible to all kinds of therapy. Do not wash down with cold water. Contra-indications have no: except for the rare cases of an allergy on vegetable oils.

- Store at dark place from 0°C up to 25°C in the closed condition no more than 2 years (Semenova, 1998).

Watermelon seed oil is light, penetrating, emollient oil, absorbs into the skin readily, dissolves sebum buildup allowing it to wash and balances the moisture in the cosmetics and hair care products for its non greasy feel and its moisturizing properties. It restores elasticity and maybe used as a natural baby oil and is a good option for a carrier oil in aromatherapy. Use in massage oils, bath oils, surface creams, bath bombs, hair oils etc. (Semenova, 1998).

2.1.5 Western Sudan watermelon:

Western region extends from the Bahr el Arab in the South to the Libyan dessert in the North and from adjacent to the Nile in the East to beyond the Jabel Mara massif in the West. This region lies mainly between the 400 mm and the 600 mm isohyets in its eastern portion and between the 400 and 800 mm in its Western portion (Robinson and Chamberlain, 1989). The North South rainfall gradient increases from about 25 mm per annum in the Northern dessert to about 900 mm along the Bahr el Arab in the South (Savanna Development Project, 1976).

Qoz soils extend over about 180,000 km^2 of Western region; they are stabilized sand dunes, products of weathering in the dessert to the North. All soils are deep and even textured throughout the whole profile with more than 90% of the particles in the coarse and fine sand fractions (Savanna Development Project, 1976). Qoz soils support the rainfed arable agriculture productivity, despite their poor actual and potential fertility. Qoz soil is 10 to 40 meters deep and fine grained of neutral pH, with negligible water holding and cation exchange capacity. Their advantages are easy manual tillage and ready release of water to extensive rooted crops especially millet, karkadeh and watermelon. The sandy texture of the soil permits extensive cultivation by a single cultivar and surprisingly good yields are obtained with reasonable rainfall. The residual soil moisture Farming techniques used for growing water melons in the West should be investigated and expanded in other areas where suitable conditions prevail (Robinson and Chamberlain, 1998). Where as Savanna Development Project Studies (1971/72) showed that although sandy soils are easily cultivated with hand tools, lose less moisture from run-off and have better soil/plant water relationships, they are of low fertility and will sustain cropping for little more than four years. The mineral status and organic matter content of the Qoz soils are low (Jewit, 1953, UNICEF Household Food, 2001).

1.7 million families depend mainly on the rainfed agriculture in their life beside the livestock subsector (Mustafa, 1999). El Fasher rural inhabitants are sedentary farmers with majority keeping ruminant livestock, notably cattle and goats (Abaker, 1990).

Mustafa (1999) reported that the rainfed subsector comprises more than 60% of the population, who are mainly producers with small size holdings and with no access to credit facilities, because most of their land are not registered to be offered as security. Due to these difficulties of obtaining their needs of money from the formal financial institutions, farmers are induced to the informal sources of credit, which in most of the cases provide their services and loans under unfavorable conditions making the farmers continuously produce for the benefit of others and not for themselves, and seek only subsistence. These informal sources include friends, shop keepers, relatives and traders practicing “Sheil” which is a traditional way of selling part of the crop before harvesting usually at low prices. Within this context the government of the Sudan in collaboration with the International Fund for Agricultural Development (IFAD), special program for sub-Saharan Africa, has established many projects in some of the rural areas. The main objectives of these projects are to fill the financial gap of small scale producers in these areas by availing agricultural credit, through credit societies, using the agricultural bank of Sudan experience in crediting system. El Nuhood Cooperative Credit Project (ENCCP) is one of these IFAD projects.

The traditional rainfed subsector suffers from lack of complete absence of extension services, research, technology and little use of inputs necessary to attain the technical packages for production. Despite these constrains and other problems, this subsector secures more than 95% of millet production in the country which is the main diet in the Western states and about 100% of the production of gum- Arabic, watermelon seed and karkadeh (Cash Crop), 17% from dura production and 22% from sesame production in country (Mustafa, 1999).

Farming system is traditional subsistence with limited resources characterized by small scale farmers, manual family labor and no external inputs such as fertilizers, chemicals or improved seeds. The faming systems are: shifting, harig and intensive cultivations. Shifting cultivation is employed in areas where land is practically unlimited and in excess of demand. Under this system of farming, certain area is brought under cultivation for a time, then the farmer moves to a new area. By this system a primitive type of rotation is practiced (AOAD and ISNAR, 1988), so soil fertility is restored but presently this system is not applicable due to narrow security zone and limited access to land (UNICEF Household Food, 2001).

Harig cultivation as with shifting cultivation can be practiced where the available land exceeds the demand, it is practiced in the fertile clay plains with thick growth of tall grass. The important feature of the system is that it uses controlled burning which cleans the land for cultivation and reduces subsequent weeding. This reduces costs and at the same time produces high yields. The normal proceed is to allow the land 2-4 years for grasses to form a dense growth. Following the first heavy rains and growth of weeds, fire is set on the dense growth, and the new young weeds are killed (AOAD and ISNAR, 1988).

In intensive cultivation, available land is intensively cultivated for several years with the same type of crops (UNICEF Household Food, 2001).

4.1 million hectare in rainfed traditional farming practiced by small farmers (AOAD, 1988) and women represent roughly 57% of the farmers in the rainfed subsector. “Jubraka” farming is practiced in a women home garden. The main crops grown are short maturity varieties of sorghum, rainfed vegetables and watermelon. Production is mainly for home consumption, and for filling the gap in the household grain needs, before the main cereal crops are harvested (Mustafa, 1999).

The traditional farmer in the rain lands uses simple cultural practices. Land preparation when carried out, consists of discing and/or ridging.

Crops are sown by hand in small holding where size depends on the availability of labor to carryout weeding and other operations. The farmer usually uses his own stock of seeds, and a wide range of varieties are planted (AOAD and ISNAR, 1988).

In Sheikan, Northern Kordofan, before the first rains, which often come in about the middle of July, farmers begin to plant seeds. Seed planting does not continue for a long period since the rainy season is of short duration (Matayo, 1998). Abaker (1990) showed that in El Fasher, Northern Darfur the axe and the rake are used in clearing the land. Seeding is done by an angled stick with a flat metal tip. While the “Seluka” which is a sort of digging stick, together with the Torya (hoe) are employed in the clay lands. Weeding is done by the “Hashasha” which is alternatively termed the “Jerraya”. Nearly, all farm tools are either locally made or purchased from nearby rural markets. Owing to the hardness of the clay soils cultivation, camels are widely employed in ploughing and seed preparations. Recently the tractor is replacing progressively the camel for similar operations on such clay lands. However, tractors are basically used in commercial crops such as tomatoes, cucurbits, pulses and tombac.

In Darfur states, watermelons are grown in August. They are usually planted when millet fails due to drought or in order to supplement income (FAO and WFP, 1992). However, Kordofan states watermelons are either intercropped with millet or grown separately depending on availability of land (Fadul, 2000).

Maturity is indicated by withering of tendrils, and increasing fruit density. Mature watermelons give a dull, hollow sound when tapped. The harvesting time begins in November.

For a small scale production, watermelon is opened at the top like a boiled egg, the center portion cut out and eaten raw with stick, the rest of the pulp is then mashed inside the rind to a watery mass which is then eaten after separating the seeds (Hussein, 1998).

For a large scale production, the medium technique was used in the form of “El Bagana” which separated the seeds. In El Nuhood Cooperative Credit Project (ENCCP), the International Fund for Agricultural Development (IFAD) manufactured model of El Bagana. It contains two units, one of them for separating the seeds and the other for animal fodder preparation. Watermelon is chopped. The pulp with its seeds is removed using “Carasha”, which is a toothed metal. The seeds and pulp are forced to pass through the openings of the plate to settle on an inclined base from which the juice flows down and pours in pots to be used as drinking water for animals and the seeds are collected to dry. It was improved by adding another plate under the first one with small aperture to retain the seeds. The capacity of this unit is 2 sacks per day, but it is not portable, with separated Carasha and a big effort is required to compress the rind.

Another design of El Bagana is driven with electric motor. Watermelons are fed and chopped with rotary knives; the fragments of the rind are retained by an opening of a shacking screen, whereas, the seeds are retained by openings smaller than the other one, and the juice flows down into a pan. The capacity of this unit is 100 sacks per day but it has high initial cost because it is drawn with car.

After separating the seeds, they are spread out on mat “El Sharagania” which is the best way manner to obtain clean seeds. The melon seeds are accumulated by producers till a substantial load is formed which is transported to the main town markets, where the seeds are screened to obtain the produce with manual screen for the small producer and electrical screen for the exporter.

In the main town markets watermelons are graded as A, B, C, … etc., according to their physical properties such as color, the percentage of foreign matter, red, brown and black seeds, the weight of 100 seeds, and the moisture content. For seed marketing, the produce is sold by auction in the crop market in a proper manner, under the supervision of the local government councils.

2.2. Physical Properties of Fruits:

The increasing economic importance of food materials together with the complexity of modern technology for their production, handling, storage, processing, preservation, quality evaluation, distribution and marketing and utilization demand a better knowledge of the physical properties of these materials. This should constitute an important and essential engineering data in machine design, structures, processors and controls, in analyzing and determining the efficiency of a machine or its operation, in developing new consumer products of plant origin, and in evaluating and retaining the quality of the final product. Therefore it is important to have an accurate estimate of shape, size, volume, specific gravity, surface area and other physical characteristics Mohesnin, 1980 and Davis, *et. al.,*1998).

2.2.1 Shape and Size:

The shape and size must be determined as important design parameters in conveying of solid material by air or water. Accurate estimates of the frontal area and the related diameter are essential for determination of terminal velocity, drag coefficient, and Reynolds number. Also shape and size are important in problems of stress distribution in the material under load, in light reflectance and color evaluation, in development of sizing and grading machinery (Mohesnin, 1980),and in determining the number of a given fruit required to fill a container by using the following equation:

$$y=b_1x_1+b_2x_2+b_3x_3+b_4x_4+b_5x_5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.2)}$$

Where; $x_1 \equiv$ shape, $x_2 \equiv$ size, $x_3 \equiv$ orientation, $x_4 \equiv$packing and $x_5 \equiv$ firmness. This relationship can be evaluated by measuring a set of specimens and magnitude of the contribution of each x to the variation in y and then $b_1, b_2, \ldots b_n$ can be determined by means of analysis of variance and multiple correlations(Quenoville, 1952).

Fruits and vegetables are irregular in shape and a complete specification of their form theoretically requires an infinite number of measurements. From practical point of view, measurement of several mutually perpendicular axes is, however, sufficient. The number of these measurement increases with increase in irregularity of the shape. It is, therefore, important to know what criterion should be used to decide when an adequate number of measurements has been made to define the form of the object. Griffith (1958) concluded that to establish such a criterion, the volume was related to the axial dimensions by using the following relationship:

$$V=a_1^{b_1}\ a_2^{b_2}\ a_3^{b_3}\ \ldots a_n^{b_n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.3)}$$

Where; V is the volume of the specimen, a_1, a_2, a_3 … a_n are diameters within the body considered as measures of size, $b_1, b_2, b_3 \ldots b_n$ are coefficients. Taking logarithm of both sides of the above equation yields the linear expression:

$$\log V= b_1 \log a_1+b_2 \log a_2 +b_3 \log a_3+\ldots+ b_n \log a_n \ldots \text{(2.4)}$$

Then by using multiple linear regression procedure (Goulden, 1952, Quenouille, 1952), volume was related to axial dimensions and the b_1, b_2,b_3 … b_n were determined using analysis of variance technique (component analysis).

Shape can be obtained by comparison with charts, resemblance to geometric bodies and sphericity (Mohsenin, 1984).By using standard chart the shape of the product can be defined either by a number on the chart or by descriptive terms, such terms were prepared for fruits and vegetables (Mohesnin, ed., 1965). Mohesnin (1980) showed examples of charts prepared for apples, peaches and potatoes. Visual comparison of the shape of the object with charted standard is a very simple technique but is a psychophysical subjective assessment which suffers from personal prejudice so that different observers achieve different results. It requires elaborate precautions and an experienced observer to ensure reasonable reproducibility (Mohesnin, 1980).

In some cases shape can be approximated by one of the geometric shape such as the prolate spheroid, spherical, and oblate spheroid depending on whether the axis ratio is less than, equal to or greater than one, respectively (Mohsenin, 1980, Baldock and Graham, 1999). The sphericity is a measure of uniformity of shape. Information of this type enables the processor to select cultivars for particular purposes. The sphericity of apples or potatoes, pears which are of uniform shape is example of describable shape uniformity characteristics (Brennan, *et. al.*, 1976).

To consider actual degree of sphericity of the fruit, the following relationship, given by Pettyjohn and Christiansen (1948) was used to determine a resistance coefficient, C_r, for calculating the terminal velocity

$$C_r = 5.31 - 4.88S \quad (2.5)$$

Where; S is the sphericity.

Based on the theories of convex bodies (Bannesen and Fenchel, 1948) it has been established that:

$$\frac{V_2}{S_3} \geq \frac{1}{36\pi} \quad (2.6)$$

Where; V is the volume and S is the surface area of the convex body. Polya and Szezo (1951) showed that the average projected area of a convex body is one fourth the surface area (S = 4A) so:

$$A \leq \left(\frac{9\pi}{16}\right)^{1/3} V^{2/3}$$

or $A \leq K\, V^{2/3}$ .... (2.7)

Where; K is a constant. For a sphere where equality is achieved, k = 1.21. This is another method for estimating the degree of sphericity of a convex body.

Curray (1951) defined the sphericity as follows:

$$\text{Sphericity} = \frac{d_e}{d_c} \quad (2.8)$$

Where d_e is the diameter of a sphere of the same volume as the object and d_c is the diameter of the smallest circumscribing sphere or usually the longest diameter of the object. This expression expresses the shape character of the solid relative to that of a sphere of the same volume. Assuming that the volume of the solid is equal to the volume of a tri-axial ellipsoid with intercepts a, b, c, and that the diameter of the circumscribed sphere is the longest intercept a of ellipsoid, the degree of sphericity can also be expressed as follows:

$$\text{Sphericity} = \left(\frac{\text{Volume of Solid}}{\text{Volume of cirumscribed sphere}} \right)^{1/3} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.9)$$

$$= \left[\frac{(\pi/6)\text{abc}}{(\pi/6)\text{a}^3} \right]^{1/3} = \left(\frac{\text{abc}}{\text{a}^3} \right)^{1/3} = \frac{(abc)^{1/3}}{a} \ldots\ldots\ldots\ldots\ldots\ldots (2.10)$$

Where; a, longest intercept, b, longest intercept normal to a and c, longest intercept normal to a and b. The intercepts need not intersect each other at a common point.

Another definition of sphericity is given by:

$$\text{Sphericity} = \frac{d_i}{d_c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.11)$$

Where d_i, diameter of largest inscribed circle and d_c, diameter of smallest circumscribed circle (Curray, 1951).

For measurement of the axial dimensions, it has been reported that the overhead projector can be used (Mohsenin, 1984). Dimensional measurements of apple consisted of two perpendicular transverse measurements and two longitudinal measurement between the upper and lower extremities of the fruit made with digital calipers (Clayton, *et. al*., 1995).The measurement of transverse diameter of unpicked apples can be done easily with a pair of calipers while the fruit is still attached to the tree (Mohsenin, 1980).

Watermelons are spherical and range from 1.4 to 45 kg, 11 kg as typical in US cultivars (Whitaker and Davis, 1962, Rice, *et. al.*, 1987) reported that watermelons are globular or oblong in shape and are up to 60 cm or more in length and 3.43 – 4.13 kg or more in weight. Watermelon can be very large and heavy up to about 20 kg, and even moderately sized fruits are difficult to handle without bruising. Small size watermelons (between 2 and 5 kg) have recently been bred in the USA (Snowdon, 1990). The Citrullus Colocynthis species of citrullus genus, 3 to 4 inches in diameter, contain small, seeds (Wakeham, 1954). Watermelon (Citrullus lanatus) fruit grown in Western Sudan is globular in shape up to the size of a man's head, smooth surfaced, white, green or stripped. The pulp is mainly white, slightly sweet, very juicy and full of seeds (Hassan, 1998).

2.2.2 Volume, Density and Specific Gravity:

Density and specific gravity of fruits and vegetables play an important role in many applications, such as, in calculating thermal diffusivity in heat transfer problems (Mohesnin, 1980), in determining Reynolds number in pneumatic and hydraulic handling of the material (Brennan, *et. al.*, 1976, Mohesnin, 1980), in predicting physical structure and chemical composition (Mohsenin, 1980), maturity evaluation (Lee, 1948), texture and softness of fruits (La Belle, 1964), estimation of air space in plant tissues (Davis, 1962) and quality evaluation of products, e. g., potatoes which increase in their density as they mature (Gould, 1957, Burton, 1938).

The irregular shape of most intact agricultural products, present certain problems in volume and density determination, so, they are usually determined by water displacement which is based on the Archimedean principle that a body suspended in a liquid has forces acting on it that make it appear to weight less than in air, the object volume is equal to the volume of water displaced. (Mohsenin, 1980, Davis, *et al.*, 1998). To prevent water from penetrating porous products paraffin coating is used. The platform scale is a simple technique which applies to large objects such as fruits and vegetables, the weight of displaced water will be used in the following expression to calculate volume:

$$\text{Volume}\,(\text{cm}^3) = \frac{\text{Weight of Displaced Water (gm)}}{\text{Weight Density of Water (gm/cc)}}$$

$$V_S = \frac{W_{CWS} - W_{CW}}{\rho_W} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.12)$$

Where $V_{S,}$ solid volume, $W_{CW,}$ weight of container and water, W_{CWS}, weight of container with water and submerged object, and ρ_w is the water density.

Knowing the weight in air and the volume, weight density of the object is then obtained by the ratio of weight to volume (Mohesnin, 1980 Davis, *et. al.,* 1998).

To determine the density, it is possible to use almost any balance which can be used to measure the apparent weight in air and also when the object is suspended into the water. To accomplish this it is necessary to find a method to suspend the object into the liquid while it is being weighed on a balance. This is normally done using either a hook to suspend the body below the balance, or an arrangement of parts to suspend the body in the liquid while it is being weighed on a special pan attached to the balance.

It is necessary to know the density of liquid. If distilled water is used the density is given below. If a liquid other than water is used it will be necessary to determine its density from tables. The density of sample is calculated from:

$$\text{Density of Sample} = \text{Density of Liquid} \times \frac{W_{air}}{W_{air} - W_{liq}} \quad \ldots (2.13)$$

Where W_{air}, weight of sample in air and W_{liq}, weight of sample in liquid (Adam Equipment Co., 2004).The specific gravity of fruits and vegetables can be determined by the water displacement method.

Specific gravity is calculated from:

$$\text{Specific Gravity} = \frac{\text{Weight in Air} \times \text{Specific Gravity of Water}}{\text{Weight of Displaced Water}}$$

$$SG = \frac{W_0}{W_{W0} - W_W} . SG_W \text{ .... } (2.14)$$

Where; W_0, weight of the object, W_W, weight of container with water, W_{W0}, weight of container with water and the object held submerged and SG_W, specific gravity of water (Mohesnin, 1980, Davis, *et. al.*, 1998).

The non destructive estimates of fruit volume are used for yield prediction. They are also used to study the relationship between fruit expansion rate and susceptibility to diseases or physiological disorders such as fruit cracking (Ngouajio, *et. al.*, 2002). After approximating the shape by one of the geometric shapes such as sphere, prolate spheroid, and oblate spherical their volume V, can be calculated using the appropriate equation. For sphere:

$$V = \tfrac{4}{3}\pi r^3 \text{ .... } (2.15)$$

Where; r is fruit radius. Selection of an appropriate value for r is difficult, given the non-spherical shape of many fruits. Clayton, *et al.*, (1995) used the average of the four dimensional measurement (two perpendicular transverse and two longitudinal measurements) as the fruit radius. The average of maximum and minimum diameters of the fruit ($\tfrac{1}{2}(a + c)$), also the geometric mean diameter ($(abc)^{1/3}$) was taken as the fruit diameter (Mohesnin, 1980).

For prolate spheroid:

$$V = \frac{4}{3}\pi ab^2 \qquad (2.16)$$

Where a is the longest intercept, b is the longest intercept normal to a for oblate spheroid:

$$V = \frac{4}{3}\pi a^2 b \qquad (2.17)$$

The estimated volume, will be compared with the actual volume and a correction factor can be established for the 'typical' shape of each variety of the product.

Ngouajio (2002) suggested a model relating bell pepper (Capsium annum), fruit diameter and length to its volume using the equation of the volume of a sphere as the starting point. The model has the following formula:

$$V_f = K\ D^2\ L\pi/6 \qquad (2.18)$$

Where V is fruit volume, K is the shape factor that varies with fruit type, D is fruit diameter, and L is fruit length. The model is simple and easy to use in the field, and may account for variations in fruit shape. Regression analyses of actual fruit volume of bell pepper measured with the water displacement method and the volume estimated using different equations showed that accuracy of the new model is comparable to that of one of the best models previously proposed. However, because the model is less complex than previous models, it is easier to use in the field.

A relationship was developed between true average projected area A (when all possible directions of projection are considered) and the volume of the object to estimate the volume as follows:

$$A \leq K\, V^{2/3} \qquad (2.19)$$

Where K is a constant. For a sphere where equality is achieved K = 1.21.The value of K was determined for lemon, potato, and carrot together with that of true sphere. According to these curves, lemon represents a nearly spherical shape while carrot represents an elongated shape. Such products as potato, apples, pears, and plums lie between these two shapes. It was found that the large variation in characteristic dimensions of such products as potatoes results in large mean probable error, also when size of the object decreases, the mean probable error increases (Houston, 1957).

No studies concerning the volume, density, and specific gravity of watermelon have been found in the previous works.

2.2.3 Surface Area:

A knowledge of surface area of fruits is important in investigations related to spray coverage, removal of spray residues, respiration rate, light reflectance and color evaluation and heat transfer studies. It is important to plant scientists as well as engineers (Mohesnin, 1980).

For measurement of surface area of fruits, such as an apple, the fruit was peeled in narrow strips and the planimeter sum of the areas of tracings of the strips was taken as the surface area of the apple (Baten and Marshal, 1943).

Another method for determining the actual surface area of apple was used by covering the fruit, including the recessed areas around the stem and apex, with 0.15 mm thick electrical insulation tape which was then sectioned and removed from the surface of the fruit, mounted onto acetate sheet and its area determined using a LI – COR model LI – 3100 area meter to the nearest 1 mm^2 (Banks, 1985). Inaccuracies associated with flattening of curved sections onto acetate were minimized by cutting the tape into narrow pieces. Accuracy of the technique was verified by covering a near perfect sphere (a solid fiber glass ball) with tape in the same way, estimation of sphere area by the tape method closely approximated the value obtained by mathematical calculation based on r (Clayton, *et al.*, 1995).

Surface areas of fruits and vegetables are often estimated by assuming that they resemble a shape from which surface area can be mathematically calculated. Such as prolate spheroid, oblate spheroid and sphere where their surface areas, S, can be calculated as follows:
For prolate spheroid:

$$S = 2\pi b^2 + 2\pi \frac{ab}{e} \sin^{-1} e \quad (2.20)$$

For oblate spheroid:

$$S = 2\pi a^2 + \frac{\pi b^2}{e} \ln \frac{1+e}{1-e} \quad (2.21)$$

Where a and b are major and minor semi-axes respectively of the ellipse of rotation and e is eccentricity given by $e = \left[1-\left(\frac{b}{a}\right)^2\right]^{\frac{1}{2}}$ (Mohesnin, 1980).

Such calculations for apples have commonly been based on perfect spheres as follows:

$$A = 4\pi r^2 \quad (2.22)$$

Where r is fruit radius. Selection of an appropriate value for r is difficult, given the non-spherical shape of many apple cultivars (Magness, *et. al.*, 1926, Hamilton, 1929, Gaffney and Baird, 1985). Ellipsoid models have also been used to predict the surface area of various products. A surface integral equation given by Wilson (1912) to determine the surface area of an ellipsoid has been utilized to estimate the surface area for apples (Baten and Marshall, 1943).Banks (1985) verified predictions obtained with this equation with another devised to calculate the surface area of an ellipsoid using a double integral equation given by Marsden and Tromba (1981):

$$A = \int_0^{2\pi}\int_0^{\pi}\sqrt{(a^2b^2\sin^2\phi\cos^2\phi + b^2c^2\sin^4\phi\cos^2\theta + a^2c^2\sin^4\phi\sin^2\theta)}\,d\phi\,d\theta \quad \ldots(2.23)$$

Where; a, b and c were the radii of the longitudinal and two transverse axes (a>b>c). Estimates of A for potato tubers derived from both ellipsoid equations yielded identical results (Banks, 1985).

A computer software package utilizing the finite element method (FEM) has been used to predict rate of heat transfer in solids of arbitrary shape (Cleland, *et. al.*, 1984) and involves calculation of surface area for the object of interest. A two dimensional axi-symmetrical coordinate grid depicting the shape of the fruit is formed which divides the fruit into a number of elements. The area is then calculated based on this grid. Correlations between area and some other easily measured physical attribute of a commodity such as mass, volume, and dimensional measurements have formed the basis for many prediction models (Baten and Marshall, 1943, Daum and Dewey, 1960, Frechette and Zahradnik, 1966, Besch, *et. al.*, 1968, Banks, 1985).Clayton, *et. al.*, (1995) estimated the surface areas of apple fruits (Malus domestica Borkh.) of four cultivars. Predictions of area for each apple by spherical analogy were made using equation (2.22) (r was based on the average of the four dimensional measurements taken from each apple). Predictions obtained by ellipsoid analogy were made using equation (2.23), values for a, b and c were based on the two transverse diameter and the average longitudinal diameter of each apple. Predicted A obtained by using FEM was obtained for each apple by entering its average transverse and longitudinal diameter into the programmes axisymmetrical coordinate grid.

Correlations were determined between actual A (by measuring the area of adhesive tape required to cover the fruit surface) and fruit mass, volume and dimensional measurements. Linear and non-linear regression models were generated from the data using SAS (Freund and Littel, 1991). The non-linear regression model as was used by Banks (1985):

$$A = d\,x^{e} \qquad (2.24)$$

Where: x mass (kg), or volume (m^3) and d, e = parameters. It was found that sphere and ellipsoid models underestimated actual surface by 15 and 18%, respectively, with poor correlation between predicted surface area and actual surface area. A method based on finite elements marginally overestimated surfaces area but reliably predicted surface area of small apples (overestimation increased with increasing fruit size) and had reasonably close correlation with actual surface area. Non-linear regression models, developed from the very strong correlation between actual surface area and both fruit mass and volume, were the most accurate predictors of fruit surface area of the methods tested. This is in contrast with the findings of a study by Frechette and Zahradnik (1966). Presumably, use of the relationship with fruit volume would reduce the risk of inaccuracy associated with cultural, seasonal, or locational variations in fruit density, compared to use of the relationship with fruit mass. The lack of a significant difference between the relationships of area with both mass and volume for different cultivars indicated that the characteristic shape of each cultivar was not an important factor influencing the ratio of area to mass or volume, this concurs with the findings of Baten and Marshall (1943).

No studies about the surface area of watermelon were found in the literature reviewed.

2.3 Properties of Seeds:

2.3.1 Shape and Size:

The dimensional relationships of an agricultural product are important in packaging, in controlling fill – in weight, and in determining the way in which materials behave during pneumatic conveying and bulk storage (Brennan, *et al.*, 1976). Mohsenin (1980) reported that the shape and size must be determined before understanding the problem of separation of seeds from undesirable materials by pneumatic or electrostatic devices. Griffith technique (1964) was used on kernels of dry-shelled corn by measuring the major, minor and intermediate axes as well as weight and specific gravity of each kernel. The volume of the kernel was taken as one of the parameters defining the shape and the three mutually perpendicular axes taken as a measure of size. The volume was related to axial dimensions. It was found that a well-defined linear relationship existed between the log of axial dimensions and log volume of corn, so the measurements of the axial dimensions (a, b, and c) supplied the bulk of information on shape and size of such irregular objects as corn kernels.

Measurements of axial dimensions for seeds can be determined by using a photographic enlarger. The seed is placed on the plane where a negative film is positioned, turned so that its shadow covers the largest area then the enlarger is focused to give a sharp boundary. A millimeter scale is also traced along with the seed image. The seed is then turned to show a minimum projection area whose long dimension is equal to the long dimension of the maximum projection area. After tracings of the projected maximum and minimum area are obtained, the a, b and c axes are measured from these drawings. The tangents to the seed outline in the narrowest area of the tracing and the perpendicular lines to these tangents are drawn. The axis is the longer of the rectangular sides, while b axis is the shorter. The same procedure is followed on the outline of the minimum projection to determine the c axis.

A faster and more accurate method is the use of a shadowgraph. The use of two micrometers in this instrument permits direct measurement of two axial dimensions for the natural rest or other positions of the seed (Mohsenin, 1980, and Mohsenin, *et., al.,* 1974).

Mohsenin showed that the average diameter of seeds and grains is calculated as follows:

- $\text{Equivalent Sphere Diameter} = \left(\frac{6}{\pi}V\right)^{1/3}$ ………………….... (2.25a)

Where V, volume of sphere equal to the volume of the object

- $\text{Geometric mean diameter} = (abc)^{1/3}$ …………………….. (2.25b)

Where, a, b and c are the axial dimensions, and

- $\text{Arithmatic mean diameter} = \left(\frac{a+b+c}{3}\right)$…………………. (2.25c)

There are different varities of watermelon seeds which vary in size and thickness of the seed edges. Basically there are small, moderate and large sized seeds edges. The seeds may be flat or moulded (Oyolu, 1977). Seeds are white, black, red or yellow, oval shaped, smooth about 0.6-1.5×0.5-0.7 cm. (Hussein, 1998). Saied (2002) found that the seeds of the variety sheiria were small, whereas Casheir, Saddir, and Farrasha (Western Sudan watermelon seeds) were moderate, and the seeds of the variety Kongo and Seinnie were large in size. Watermelon seeds of most varieties showed more or less similar lengths and widths. They fall in the range of 1.2-1.3 cm for length and 0.6-0.7 cm for width. However, seeds of the varieties of Kongo and Sheiria recorded the highest (1.8×0.9 cm) and the lowest (0.9×0.62 cm) measurements of (Length × Width) respectively. Also the whole seed weight, the kernel and hull relative weights were determined for different varieties of Western Sudan watermelon seed varieties such as Casheir, Saddir, and Farrasha (Table 2.3).

Table (2.3): Whole seeds weight and hulls and kernels relative weights of western Sudan watermelon seed varieties

Variety	Weight of Whole Seeds (mg)	Weight of Hulls (mg)	Weight of Kernel (mg)
Casheir	0.10587	0.0475 (44.53)*	0.0565 (53.57)*
Saddir	0.0985	0.0453 (45.88)	0.0544 (55.49)
Farrasha	0.1028	0.0441 (42.82)	0.0542 (52.83)

* Weight of hulls and Kernels as percent of whole seeds.

The study revealed that, the seeds of rainfed varieties of watermelons are the best to be employed in broiler ration, because of their higher kernels relative weights, higher whole seeds weights.

2.3.2 Volume and Specific Gravity:

The small size of seeds presents certain problem in volume measurement, so, the volume of seeds is determined by water displacement. An analytical balance or more conveniently a specific gravity balance can be used to determine volume, density and specific gravity employing the following expressions:

- If the solid is heavier than water;

$$\text{Volume} = \frac{\text{Weight in Air - Weight in Water}}{\text{Weight Density of Water}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.26)}$$

$$\text{Specific Gravity} = \left[\frac{\text{Weight in Air}}{\text{Weigh in Air - Weight in Water}}\right][S\,G_L] \ldots\ldots \text{(2.27)}$$

Where SG_L is the specific gravity of water.

- If the Solid is lighter than water, another solid heavier than water is attached to the object as a sinker and the specific gravity is determined from:

$$\text{Specific Gravity} = \left[\frac{(Wa)_{object}}{(W_a - W_W)_{both} - (W_a - W_W)_{sinker}}\right][SG_L] \ldots\ldots \text{(2.28)}$$

Where W_a = weight in air and W_W = weight in water. (Mosenin, 1980).

A solution of 3cc wetting agent in 500cc distilled water will reduce errors due to surface tension and submergence in water.

A fast and accurate method for determining volume and weight density of small seeds is the use of specific gravity gradient tube. The technique is based on observing the level to which a test specimen sinks in a liquid column exhibiting a density gradient in comparison with standard glass floats. The only requirement is that the specimen must be impervious to the liquid in the column until the liquid and test specimen have reached equilibrium and reading is obtained. To determine the specific gravity, the specimen is placed gently in the tube allowing the liquid and specimen to reach equilibrium. At this time the height of the specimen in the tube is read and by reference to a calibration curve the specific gravity is determined. If equilibrium is not obtained, liquid may be penetrating the specimen. The calibration curve is merely a plot of float position versus float specific gravity. If a calibration chart is not available, a method of interpolation can be used employing the following expression:

$$\text{Specific Gravity at X} = a + \frac{(x - y)(b - a)}{(z - y)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.29)$$

Where; a and b are specific gravities of two standard floats.

y and z are distances of the two standard floats a and b, bracketing the unknown, respectively, measured from a reference level.

x is distance of the unknown from the same reference level.

A wire screen basket attached to a long wire and an electric clock motor forms an elevator for removing the old specimen from the tube at such a slow rate so that the gradient is not disturbed. The accuracy of the technique depends on gradient of specific gravity of the liquid per mm height of the column. Columns with sensitivities as high as 0.0001 per mm height can be constructed.

Air comparison pycnometer is a commercially available instrument for volume measurement. It consists basically of two chambers and two pistons, a valve connecting the two chambers, a differential pressure indicator, and a digital counter calibrated for readings in cubic centimeters. With the connecting valve is closed any change of the position of one piston must be duplicated by an identical stroke in the other in order to maintain the same pressure on each side at a certain amount to any given position. Inserting a sample in the measuring chamber would cause a pressure differential which is brought to zero by withdrawing the piston in this chamber. Under this condition, the distance that the measuring piston differs from its position before inserting the sample will be proportional to the volume being measured. This instrument measures the true volume of a sample. For measurement of the apparent volume, the manufacturer recommends filling the pores first by immersing the sample in a molten wax bath. Knowing both the apparent and true volume of a sample the porosity can be obtained, so this instrument is used to determine the bulk density of grains (Mohsenin, 1980).

The liquid pycnometer is a relatively simple device suitable for measuring volumes of solids or bulk granular materials that do not absorb liquid readily such as seeds. The liquid replaces air in the pores or around the solid so that the solids displace a volume of liquid equal to the volume of the particles or solid object. This total volume is calculated from the weight of the liquid displaced by the solid as follows:

$$V_S = \frac{\left[W_{PW} - W_P\right] - \left[W_{PWS} - W_P - W_S\right]}{\rho_W} \quad \text{.....................} \; (2.30)$$

Where $V_{S,}$ specimen volume (cm^3), $W_{S,}$ weight of specimen, g, W_P weight of empty pycnometer, g, $W_{PW,}$ weight of pycnometer filled with water, g, W_{PWS} weight of pycnometer containing solid and filled with water, g, and ρ_w water density g/cm^3.

The method of specific gravity bottle or pycnometer and toluene has been the practice for many years (Baiely, 1912). Toluene ($C_6H_5CH_3$) has the advantages such as has little tendency to soak into the kernel, a low surface tension, enabling it to flow smoothly over the kernel surface, little solvent action on constituents of the kernel especially fats and oils, a fairly high boiling point, and not changing its specific gravity and viscosity materially on exposure to the atmosphere and having a low specific gravity (0.87 to 1.59).

Specific gravity of the batch of toluene is determined by comparing the weight of toluene which the bottle holds with the weight of the distilled water at the same temperature (20°C), then:

$$\text{Specific Gravity of Toluene} = \frac{\text{Weight of Toluene}}{\text{Weight of Water}} \ldots\ldots\ldots\ldots\ldots \text{(2.31)}$$

Specific gravity of the seeds is calculated from:

$$\text{Specific Gravity of Seed} = \frac{\text{Specific Gravity of Toluene} \times \text{Weight of Seed}}{\text{Weight of the Toluene displaced by the Seeds}} \ldots \text{(2.32)}$$

Weight of toluene displaced by the seed is found by subtracting the difference in bottle weights when filled with toluene and when containing the seed from the weight of the seed.

Volume of sample is calculated from:

$$\text{Volume of Sample} = \frac{\text{Weight of Seeds}}{\text{Specific Gravity of Seeds} \times \text{Weight density of Water}}$$

……(2.33)

No studies concerning the volume, density and specific gravity of watermelon seeds have been found in the previous work.

2.3.3 Moisture Content:

Moisture content of a product is the quantity of water held by it. It is a numerical value expressed in percentage by weight. Therefore, when the moisture content of a product is reported, the basis used (wet or dry) should be specified (Davis, *et. al.*, 1998).

The moisture of agricultural products of plant origin exerts a profound influence on their physical properties. This influence is of major concern in proper storage, handling and processing of these materials (Mohesnin, 1980).Taylor (1994) concluded that the seed content with high lipid content have a lower equilibrium. Moisture content at a given relative humidity than a seed with low liquid content, as lipids have little affinity for water.

2.3.3.1 Methods of Determination:

It is necessary to quantify the water in seeds and express the water in meaningful units. Moisture can be determined using either primary or secondary methods.

Primary Methods:

The primary procedures are such that the moisture in a sample is removed and the quantity is determined by weighing or measuring. They are used to obtain highly accurate moisture measurements. The values obtained from primary methods are used to calibrate all secondary types of moisture-measuring devices, the procedures used in the primary methods are too cumbersome and time-consuming for most application such as measurement on farm, at warehouses, and industry.

Primary methods include air-oven drying, vacuum-oven drying and the fractional distillation process (Davis, *et. al.*, 1998).The moisture content may be calculated and presented in different ways. Seed moisture content calculated on wet weight basis is commonly used in seed testing and commerce, while the moisture content presented on a dry weight basis may be found in physiological or biophysical literature. The following formulas are used to determine the percentage of seed moisture content on a wet and dry weight basis.

$$\%\text{Misiture content}(\text{wet basis}) = \left[\text{weight of water}(\text{dry weight of seed} + \text{weight of water})^{-1}\right] \times 100$$

.. (2.34)

$$\%\text{Mositure content(dry basis)} = \left[\text{weight of water (dry weight of seed)}^{-1}\right] \times 100$$
… (2.3)

For comparison the two methods of expressing the percentage of moisture content can be converted by the following equations:

$$\%\text{Mositure content (dry basis)} = 100 \times \%\text{ mositure content(wet basis) (100 - \% mositure content (wet basis))}^{-1}$$
… (2.36)

$$\%\text{Mositure content (wet basis)} = 100 \times \%\text{ moisture content(dry basis) (100 + \% moisture content(dry basis))}^{-1}$$
… (2.37)

Secondary Methods:

Secondary methods which are faster and usually dependent on electrical or electromagnetic properties of the product are most often used. They include dielectric or capacitance – type moisture meters (e. g., Dickey – John or Motomco moisture meter), resistance – type moisture meters, and chemical – type moisture measuring devices (Davis, *et. al.*, 1998). In Dickey – John or equivalent moisture meter, the selected specimen is placed between two capacitor plates. The capacitance of condenser varies with the moisture content of a material, degree of compaction and the temperature. Devices that measure the electrical resistances of products are calibrated against oven determinations and are adequate for many tests. Since resistance varies with the distribution of moisture within the material, with material density and perhaps with acid index and other factors and since the characteristics of moisture meter itself change with time, exact results can not be expected. Material removed from a drier for a moisture check has a moisture gradient through each element and may also yield unsatisfactory results (Henderson and Perry, 1976).

Alkhalifa (1996) reported that the moisture content of watermelon seeds from different places was found to be 2.61% (wet basis) for an Egyptian watermelon seeds, 3.14% (wet basis) for an Iranian and 3.24% (wet basis) for Chinese watermelon seeds. Yousif (1992) showed that the moisture content of a Sudanese watermelon seeds especially types obtained from Western Sudan is 2.8% (wet basis), whereas, Hussein (1996) reported (2% wet basis). Hussein (1994) reported 3.45% (wet basis) near to 3.5% (wet basis) which was determined by Rizgalla and Mabrouk (1999).

The moisture content of watermelon (*Cirrullus vulgaris*) seed variety baladi 3.45% (wet basis). (Hussein, 1994) near to 3.5% (wet basis) which was determined by Rizgalla and Mabrouk (1999).Mustafa, *et. al.*, (1972) found that the moisture content of the whole seeds, kernel and hull of watermelon seeds were 4.94, 3.99 and 6.94% (wet basis) respectively. This result was in a reasonable agreement with the reports of Oyenuga (1968), Kuzayli, *et. al.*, (1966) and Hassan (1998). The maximum limit of watermelon seeds moisture content is 6% (wet basis) according to the Sudanese Specification for watermelon seeds (2005). Saied (2002) determined the percentage of dry matter of different watermelon seeds varieties (Table 2.4).

Table (2.4): The dry matter percentage of different watermelon seeds varieties:

Variety	Dry matter %
Casheir	97.2
Saddir	97.1
Farrasha	97.1
Kongo (Kosti)	95.9
Kongo (Gezira)	96.4
Kongo (Mixture)	97.0
Seinnie (Dopa)	97.7
Sheiria (Mixture)	97.3

Sheiria (Dopa)	96.4

The low moisture content of watermelon seeds accompanied with its very high dry matter content which may contribute substantially in keeping quality of the seeds even if it is transported for long distances and stored for considerable periods of time.

2.3.4 Oil Content:

Most of the fruits of cucurbitaceous family bear numerous seeds and in view of the fact that these usually are moderately rich in fat, the relatively little practical use that has been made of them as oil seeds may seem surprising. Several investigations recently have called attention to what they consider to be undeveloped possibilities among these plants as producers of oil seeds. In properties and composition, the fats of this family show an interesting diversity (Wakeham, 1954).

Vegetable oils industry in Sudan is regarded as one of the ancient industries. It started as a primitive industry utilizing the animals as a source of grinding for the extraction of crude oil from sesame and groundnuts. Lately, Sudan is considered as one of the greatest Arab potentials in the field of vegetable oils industry.

2.3.4.1 Methods of Extraction:

Over the centuries, four basic methods of extracting vegetable oils from the various seeds, nuts and fruits have been established. The oldest treatment was the basic wet rendering process in which the oil-bearing material was boiled in water leading to a partial separation of oil, which was eventually skimmed off the top of the vessel. The second method was the cage – type press in which pressure was exerted on a stationary mass by levers, screw jacks or hydraulic cylinder and the vegetable oil is forced to flow from the compressed mass to collection rings below, both of these methods are more or less obsolete. The third method is the mechanical screw press and the fourth one is the solvent extraction (Baiely, 1964 and Bredson, 1983).

1. Mechanical Extraction:

Mechanically adherent mineral or vegetable matter is removed first from the seeds in the first stage of their passage from the store to the extractors by combination of shaking and screening machinery. Two classes of crushing – machine or rolls are employed, namely: reducing and finishing. The reducing rolls are employed for preliminary breaking down of the larger seed such as groundnuts and consist of two, three, or four pairs of rolls through which the seed is successively passed. By this means seeds are broken down into fragments sufficiently small to be dealt with adequately in the finishing rolls. Correct milling is essential to high efficiency of oil yield, especially in modern hot pressing. The resulted meal is transferred as rapidly as possible and fed, in to the extraction vessels. However, in the cold-pressing the meal is packed directly into the press, but for hot-pressing a further intermediate stage is required between the finishing rolls and the presses, namely ‘cooking’. This is effected in steam-jacket closed vessels provided with mechanical stirring gear, into which the meal is charged and warmed up carefully with slow agitation to about 50-60 ˚C. The amount of moisture in the seed during ‘cooking’ has an important effect on the subsequent expression of oil. For extraction in hydraulic presses, a moisture content of about 7-9% in the meal gives the best results, but the optimum proportion varies to some extent with the oil-seed concerned. In either cold or hot pressing the processes may be carried out in plant of a variety of type, the pressing industry has developed very considerably in recent years and much high pressure are now in general use than was the case formerly (Ajibola, 1990).

In 1903, Anderson invented a screw – press for continuous extraction of oil from seeds by pressure which has become known as an oil expeller. Material trapped between the screw and the inside of the cylinder barrel passes through a gradually reduced flow area. The walls of the cylinder contain fine perforation or slots covered by adjustable screens, through which the extracted liquor drains from the cake. The expelled oil meal is produced as a compact cake which is flaked off by a conical projection mounted at the discharge end of the box in which the screw conveyor operates (Alder Wright, 1965).

Hassan (1998) used three different mechanical oil extraction techniques to press watermelon seeds obtained from Eldhein, Foga and Umsayal. These techniques are: motorized camel ghani, Chinese ZX10 model, and Chinese ZX10 model fitted with a boiler jacket and a cooking device at the inlet side of the seed. Motorized camel ghani consists of a large steel pestle and mortar, the power source is a diesel engine or electric motor, “15 and 10 hp respectively” instead of the camel in the conventional types. The drive system consists of a lorry or car gearbox and shafts, supported on steel frame structure. As the engine runs on, seeds are pressed by the rolling action of the pestle on the mortar "the pestle looks like a roller". The speed of the pestle was 6 rpm. There is a hole at the lower end of the mortar to allow the oil to squeeze downwards.

Chinese presser ZX10 model constructed from helical screw, surrounded by a series of hundred rings with small grooves that let the oil out, throughout the length of the screw. Cake extruded from the back end of the screw through a restricted adjustable outlet. The helical screw is designed in manner that exerts pressure on the fed seeds throughout the length of the screw as well as grinding action at edges. The screw is powered via a pully arrangement at 30 rpm from 10-15 hp electric motor. The characteristics of the previous techniques were compared with Rose Down engine in which the materials to be extracted is continuously fed, then it is sprayed with a number of streams of solvent, before it is discharged (Table 2.5).

Table (2.5): The Characteristics of different pressing engines:

Characteristics	Electrical Ghani	Chinese I	Chinese II	Rose Down
Power rating (hp)	10-15	10-15	10-14	240.5
Speed (rpm)	6	30	30	22-48
Wt. pressed/hour (kg/hr)	9	10.28	16.5	2000
Yield/hour (litre/hr)	1.3521	1.6471	2.1761	329.761
Oil%	16.4%	17.5	14.5%	18%
Oil% in the cake	8.41%	8.2%	11.2%	8%
Pressing repetitions (times)	1	5	1	1
Extraction efficiency of 26.8% oil content	61%	65%	54%	70%

Baiely (1996) reported that power consumption in these units is high. Power is dissipated in friction and may raise the product temperature appreciably. The degree of comparison achieved can be varied by adjusting the area of discharge port and by varying the speed of rotation of the worm, but It is well known that extraction by a pressure is a system that is generally favored as yielding the highest grades of oil, since minor amounts of non-fatty materials are less readily extracted from the seed by pressing than by the application of solvents, and there is no question of the presence of traces of solvents left in the finished.

The local method of oil extraction from watermelon seeds consists of manually shelling the dried seed, cleaning, cooking and then grinding with pestle and mortar. The oil is extracted by squeezing the ground samples by hand or on a hard smooth platform inclined gently to the horizontal. This method is slow, inefficient and intensively laborious. Recent needs have, however, motivated the production of watermelon seed oil on a large scale with the use of screw and hydraulic presses (Ajibola, *et. al.*, 1990).

Investigations were conducted on the mechanical expelling of oil from watermelon seeds (*Citrullus Vulgaris*). The processing variables were particle size, moisture content, heating temperature and time. Oil yields from finely ground samples being significantly higher than oil yields from coarsely ground samples. Indeed, oil yield was significantly affected by the reduction in moisture content during heating with the maximum yields being obtained when the moisture content of sample was reduced by about 5% during heating. It has been reported that by proper selection of initial moisture content, heating temperature and heating time, yield of about 40% can be obtained from watermelon seeds at an expelling pressure of 25 MPa. Processing condition at the levels used did not affect the color, specific gravity, refractive index and viscosity of watermelon seed oil for the range of variables considered in that study, a maximum oil yield of 41.6% was obtained when finely ground melon seeds, conditioned to a moisture content of 9.2% were heated at 130°C for 20 min and pressed at 25 MPa (Ajibola, 1990).

Sudanese-Arab Vegetable Oil Company pressed the whole watermelon seed (Rose Down engine, 1995) and found this equipment gives an extraction efficiency of 70% from 26.8% oil content of the whole seed. It has been concluded that, watermelon seeds when intended to be pressed as whole seeds need more horse power engine than that working on decorticated seeds. Moreover, the pressed kernel will have additional advantage of producing cakes rich in protein and minerals. The study suggested that more investigations need to be conducted on decortications of watermelon seeds to facilitate oil extraction.

The oil content in watermelon seed cake was determined by many researchers, e. g., Rizgalla, Musaad, (1998) and Mohammed (2000) who suggested 8.06, 7.5 and 9.2% respectively. A lowest content was reported by Kaduskar, *et. al*, (1980) is 1.9% but the oil content in the results (meal) after solvent extraction was less than 1% and can be as low as 0.5%.

Moreover it has been found that watermelon seed oil produced by a mechanical extraction has a pale yellow color (Ajibola, 1990). Locally watermelon seed oil obtained from Western Sudan was found to have light color (extracted by solvent) (Mustafa, 1972).

2. Solvent Extraction:

The extraction of a soluble constituent from a solid by means of solvent is generally referred to as leaching. With seeds such as, soy beans containing only about 15% of oil, solvent extraction is often used because mechanical methods were found to be very efficient (Coluson and Richardson, 1968).

Generally the leaching process can be considered in three parts: First the change of phase of the solute as it dissolves in the solvent, secondly its diffusion through the solvent in the pores of the solid to the outside of the particle, and thirdly the transfer of the solute from the solution in contact with the particles to the main bulk of the solution. Anyone of these three processes may be responsible for limiting the extraction rate, but the first process usually occurs so rapidly that it has a negligible effect on the overall rate (Coluson and Richardson, 1968).

The selection of the equipment for an extraction process is influenced by the factors which are responsible for limiting the extraction rate such as the particle size, solvent, temperature and agitation of the fluid.

It is generally desirable that the range of particle size to be small and uniform so that each particle requires approximately the same time for extraction.

The liquid chosen should be a good selective solvent and its viscosity should be sufficiently low for it to circulate freely. Generally a relatively pure solvent will be used initially, but as the extraction proceeds the concentration of solute will increase and the rate of extraction will progressively decrease, first because the concentration gradient will be reduced, and secondly because the solution will generally become more viscous (Coluson and Richardson, 1968).

The solvents used are usually light petroleum fractions of the hexane (BP 63.5-69°C) or heptane (BP 90-99°C) type. Cyclic hydrocarbons such as cyclohexane (BP 71-85°C) are also used. Such solvents are highly flammable and great care is necessary in their use.

Non-flammable solvents such as trichloroethylene (BP 86.5°C) have also been used but they are toxic and also difficult to handle and with certain products the spent cake is itself toxic to cattle. Recently considerable interest has been expressed in the use of isoproply alcohol and ethyl alcohol as solvent.

In most cases, the solubility of the material which is being extracted will increase with temperature to give a higher rate of extraction. Further the diffusion coefficient will be expected to increase with rise in temperature and this will also improve the rate. Agitation of the solvent is important because it increases the eddy diffusion and therefore increases the transfer of material from the surface of the particles to the bulk of the solution (Coluson and Richardson, 1968). Leaching has in the past been carried out mainly as a batch process but many continuous plants are now being developed. The type of equipment employed depends on the nature of the solid – whether it is granular or cellular and whether it is coarse or fine. The normal distinction between coarse and fine solids is that the former have sufficiently large settling velocities which make them to be readily separable from the liquid, whereas the latter can be maintained in suspension with the aid of only a small amount of agitation. Generally the solvent can be allowed to percolate through beds of the coarse materials, whereas the fine solids offer too high a resistance. The rate of extraction will, in general, be a function of the relative velocity between the liquid and the solid. In some plants the solid is stationary and the liquid flows through the bed of particles, while in some continuous plants the solid and liquid move counter currently (Coulson and Richardson, 1968).

A batch plant consists of a vertical cylindrical vessel divided into two sections by a slanting partition. The upper section is filled with the charge of seeds which is sprayed with fresh solvent from a distributor. The solvent percolates through the bed of solids and drains into the lower compartment where, together with any water extracted from the seeds, it is continuously boiled off by means of a steam coil. The vapors are taken to an external condenser and the mixed liquid is passed to a separating box from which the solvent is continuously fed back to the plant and the water is run to waste. By this mean a concentrated solution of the oil is produced by the continued application of pure solvent to the seed (Coulson and Richardson, 1968).

The Bollomann Continuous Moving Bed Extractor consists of a series of perforated baskets arranged as in a bucket elevator, contained in a vapor-tight vessel, and is widely used with seeds which do not disintegrate on extraction. Solid is fed into the top basket on the upward side. The solvent is sprayed onto the solid which is about to be discarded, and passes downwards through the baskets so that countercurrent flow is achieved. The solvent is then finally allowed to flow down through the retaining baskets in co-current flow. A typical extractor will move at about 1 revolution per hour with each basket containing about 800 Lbs of seeds. Generally about equal weights of seeds and solvents are used and the final solution, known as miscella, contains about 25% of oil (Goss, 1946).

The Bonotto extractor consists of a tall cylindrical vessel with a series of slowly rotating horizontal trays. The solid is fed continuously on to the top tray near its outside edge and a stationary scraper, attached to the shell of the plant, causes it to move towards the center of the plate. It then falls through an opening on to the plate beneath, and another scraper moves the solids outwards on this plate which has a similar opening near its periphery. By this means the solid is moved across each plate, in opposite directions on alternate plates, until it reaches the bottom of the tower from which it is removed by means of s screw conveyor. The extracting liquid is introduced at the bottom and flows upwards, so that continuous countercurrent flow is obtained, but a certain amount of mixing of solvent and solution takes place when the density of the solution rises as the concentration increases (Goss, 1946).

Rose Down continuous extractor consists of a cylindrical tank in which 18 sector shaped perforated cells slowly rotate. The material to be extracted is continuously fed in at a fixed point at such a rate that the cell is filled in the time taken to pass the feeder. It is then sprayed with a number of streams of solvent, each successive streams being more dilute than the previous one and finally with pure solvent before it is discharged (Coulson and Richardson, 1968).

Seeds of cucumbers, melons and watermelons were analyzed (New Delhi), oil content of kernels varied from 41-56.5% (Madaan and Lai, 1984).The oil obtained from the watermelon seeds (*C. Vulgaris*) ranged from 20 to 40 percent of the whole seed. It was yellow to greenish colored oil which melts at –11°C. Table (2.6) gives the oil content of watermelon seeds from ordinary type of watermelon and from a picking variety (*Citron*). It was found that the Fatty acid composition and properties of the oil indicated that it was good edible oil.

Table (2.6): Oil content of different species and varieties of *citrullus*:

Species	*Vulgaris*	*Vulgaris*	*Colocynthis*	*Naudinianus*

Variety	Cuban Queen	MA 49242*		
Geographical Source	Florida	Texas	Sahara Desert	
oil, % in seed	26.5	19.3	18.1	15.3

* The number is designation of Texas Agricutlural Experiment Station for the Varity

Source: Vegetable Fats and Oils (Wakenam, 1954).

It has been reported that watermelon (*Citrullus Vulgaris*) (Ontario-Canada) has 23.1% fat content of kernels (Kamel, *et. al.*, 1985). In China the seeds of 3 edible seeds watermelon lines (SW-1, SW-2, and SW-3) were analyzed. The crude fat contents for SW-1, SW-2, SW-3 were 38.69, 44.36 and 47.93%, respectively, and similar to African lines in this respect (37.7 to 46.8%) (Zhang, *et. al*, 1990). In India watermelon (*Citrullus Vulgaris*) and Sugar Baby cultivars were analyzed for their chemical composition. The oil content varied from 45.3-56% which were comparable with conventional oil seeds such as groundnut, oil contents sesame, rape seed and Brassica. The chemical composition of long melon and watermelon seed kernels and hulls was reported at Punjab (India). The kernels were rich in fat (46.5-52.2%). In Nigeria, watermelon seeds analysis revealed that the seed contains high amount of fat (50.6-55.4%).

In Sudan, Saeid (2002) determined the oil content of the different varieties of watermelons seeds grown in rain fed and irrigated regions (Table 2.7).

Table (2.7): Oil content of different varieties of watermelon seeds:

Variety	Ether Extract (%)
Casheir	20.8
Saddir	23.8
Farrasha	23.5
Kongo (Kosti)	19.8
Knogo (Gezira)	21.0

Kongo (mixture)	25.0
Seinnie (Dopa)	21.0
Sheiria (mixture)	27.5
Sheiria (Dopa)	25.0

The different varieties were mixed and analyzed. The oil content of raw watermelon seeds and treated (roasted) watermelon seeds were found 27.88 and 30.18%, respectively. It was concluded that roasting of watermelon seeds led to an improvement in the apparent retention of crude protein which was significant at higher level of inclusion. The study revealed that the higher contents of ether extract oil in the full fat watermelon seeds make it difficult to grind the seeds before being incorporated in broiler rations. This has been overcome by mixing the seeds with the major feed ingredients prior to grinding.

Mustafa, *et. al.*, (1972) determined the oil content of different varieties of Western Sudan watermelon seeds (Table 2.8).

Table (2.8): Oil content of different varieties of western sudan watermelon seeds:

Variety	Weight (gm)	Oil Content (%)
Black	10.58	28.66
Gray	11.93	26.81
Mottled black	12.41	26.53
Mottled yellow	23.05	25.87
White	72.03	26.02

Source: The First National Committee for Food Processing, Sudan (1973).

The oil content of kernel and seed coat were 50.64% and 0.78% respectively. The results were similar to that obtained by Hassan (1998) where the oil content of the kernel and the seed coat of Eldhein watermelon seed as 47.3 and 0.83%, respectively. These results are in a reasonable agreement with earlier reports of Oyenuga (1968) Kuzayh, *et. al.*, (1966). In addition to Eldhein watermelon seeds, the oil content was determined to Umsayal and Foga watermelon seeds (Table 2.9). The study showed that the high level of linoleic acid content (63.4%) qualified watermelon seed oil as an excellent source for this important fatty acid, (Hassan, 1998).

Table (2.9) Oil Content of watermelon seeds from different localities in western Sudan:

Locality	Oil%
Umsayal	25.8
Foga	26.0
Eldhein	26.8

The oil content of Western Sudan watermelon seeds lies between 18-28% according to the Sudanese Specification for watermelon seeds (2005). All the determined values mentioned above were within the specification.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials:

This research project was conducted in December 2003at the laboratories of Faculty of Engineering and Architecture, University of Khartoum. Then it was conducted in December 2004 at the Faculty of Education (Dept.of Biology), University of Juba. The oil content determination was made at the Food Processing Center, Shambat.

3.1.1 Equipment Used:

The general equipment used in conducting the experimental work for this research included a sinker rod, container, thermometer, pebbles as sinker, measuring cylinders, ruler, vegetable peeler, paring knife, filter paper, moisture dishes, polythene bags, desicator contains alumina as desiccant, pestle and mortar and a thimbles. Moreover, the apparatus involved in the research work were as follows:

1. Digital platform scale: This scale (model TFW 60) having a range of 100 g to 60 kg (Fig.3.1). It was used for measurement of watermelon volume, density and specific gravity. It was made in England by Adam Equipment Co.

2. Overhead projector: It was used for measurement of watermelon dimensions (Fig.3.2).

3.Digital planimeter: The planimeter (model KP-90 N)having 10m^2 as a maximum cumulative area and accurate within 0.2 % (Fig. 3.3). It was used for measurement of watermelon surface area. It was made in Japan by Placom Co.

4. Digital Hotbox oven: The oven (model OHF097.XX 2.5) was afan type, having a temperature range of 30 to 200 C (Fig.3.4). It was used in determination of watermelon seeds moisture content. It was made in England by Sanyo Gallenkamp PLC.

5. A sensitive balance to the nearest 0.001 g was used to weigh the watermelon seeds for moisture content determination.

6. Pycometer 50 ml, Gay Lussac: It was used with toluene to determine the specific gravity of watermelon seeds (Fig.3.5).

7. Soxhelt extractor: It was used with hexane to determine the oil content of watermelon seeds (Fig.3.6)

Figure (3.1): Digital Platfrom Scale TFW 60 (Adam Equipment Co.) for measurement of watermelon volume, density and specific gravity

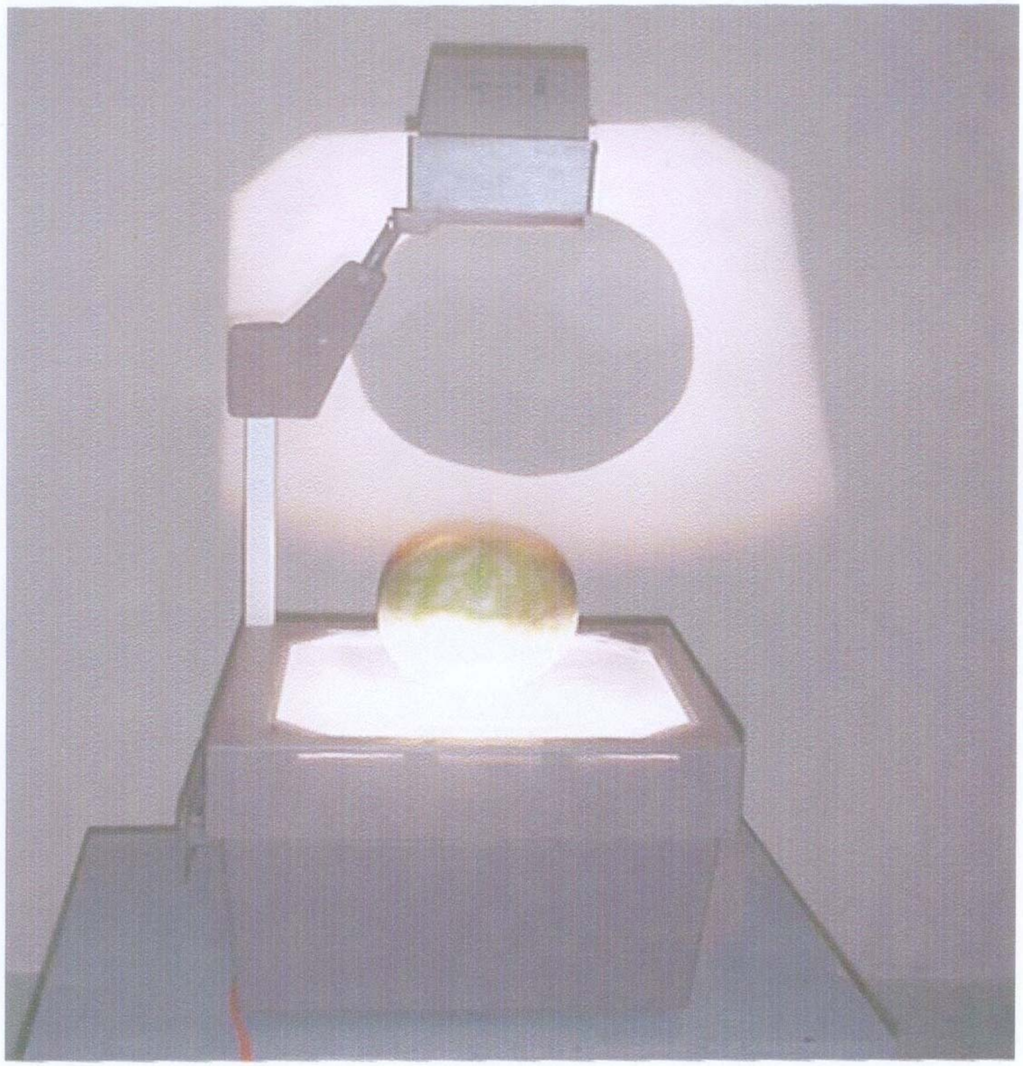


Figure (3.2): Overhead Projector for Measurement of Watermelon Dimensions

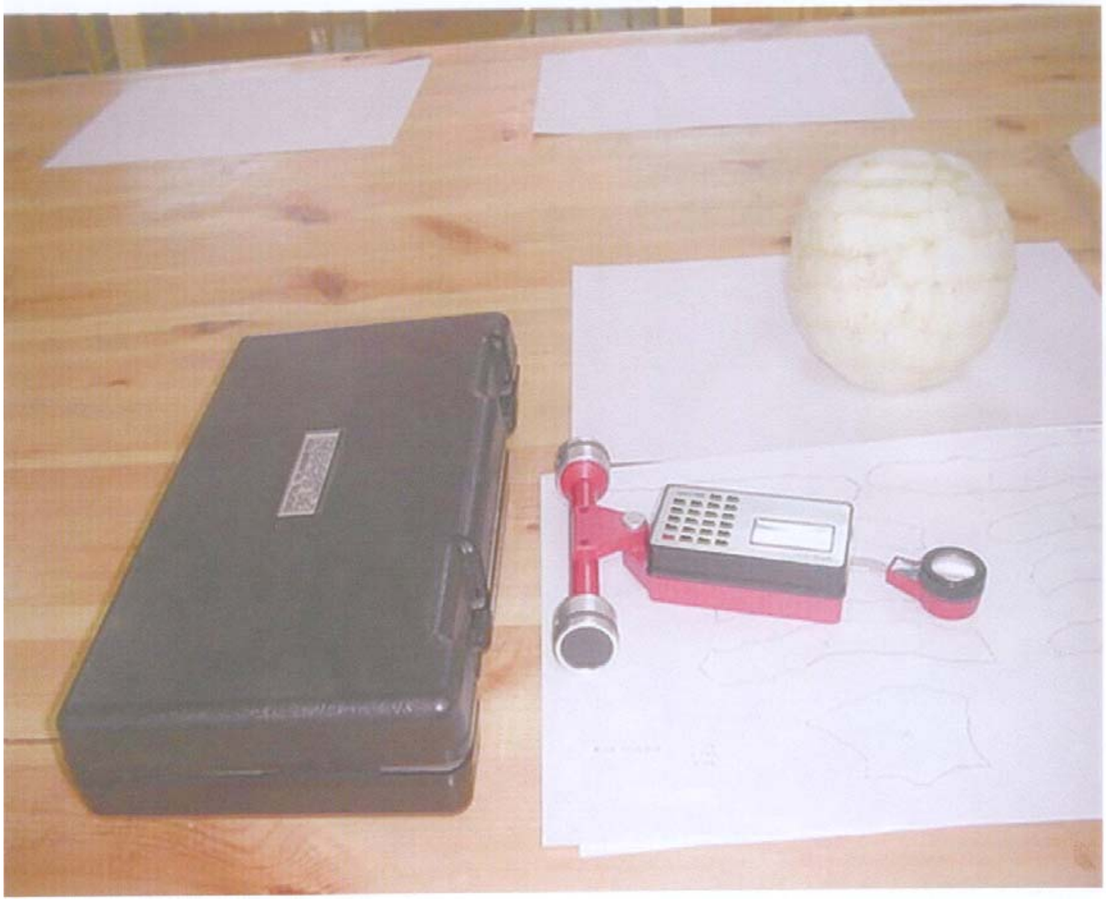


Figure (3.3): Digital Planimeter KP-90 N (Placom Co.) for Measurement of Watermelon Surface Area

Figure (3.4): Digital Hot Box Oven OHF 097.XX 2.5 (Sanyo Gallenkamp Plc.)

Figure (3.5): Pycnometer 50 ml, Gay Lussac for measurement of watermelon seeds specific gravity.

Figure (3.6): Soxhelt Extracting Apparatus

3.2 Methods:

3.2.1 Collection of Samples:

Samples of Western Sudan watermelon (*Citrullus vulgaris*) were brought from Eldhein (Western Darfour). The samples were collected at random from two consecutive seasons. In the first season (2003/04), a quantity of only 26 small-sized watermelons were obtained due to bad harvest. In the second season (2004/05), 67 watermelons were obtained from various size ranges, for further investigations (Fig. 3.7). Different varieties of watermelon seeds were extracted.

3.2.2 Experimental Design:

The actual volume of watermelon was determined using the water displacement method and then the watermelon density and specific gravity were determined. The measured dimensions of each fruit consisted of three axial dimensions which were measured using the projection method. The fruit volume was related to the measured dimensions using the multiple linear regression model. The fruit shape was resembled by three geometric shapes (sphere, oblate spheroid and prolate spheroid).The predicted volumes using these three models were determined and related to the actual volumes.

The actual surface area of watermelon was determined using the peeling method. Then the rind thickness was measured. The sphere, oblate spheroid and prolate spheroid models have also been used to predict the fruit surface area. These predicted surface areas were linearly related to the actual surface areas.

Figure (3.7): Samples of Western Sudan Watermelon

The fruit surface area was related to its weight and volume using linear and non – linear regression models. The predicted surface areas using these two models were linearly related o the actual surface areas.

The initial moisture content of watermelon seeds was determined using an air oven method. Then the specific gravity of these seeds was determined using the method of pycnometer and toluene. The seeds were graded according to the Sudanese specification for watermelon seeds. The oil content of each group of watermelon seeds grade was determined using the solvent extraction method.

3.2.3 Experimental procedures:

3.2.3.1 Volume, Density and Specific Gravity of Watermelon:

The actual volume of watermelon was determined by water displacement method using the platform scale technique for the first season samples according to Mohsenin (1980). The fruit was weighed in air and then forced into the water by means of a sinker rod (tared weight). The weight of displaced water was determined by subtracting the weight of container and water from the second reading of the scale with the submerged fruit. Weight density of water was obtained (Lide, 1994) after measuring temperature. The volume was calculated by dividing the weight of displaced water by the weight density of water. Accuracy of this technique was verified by determining the actual volume of a perfect sphere (ball) in the same way. Determination of a sphere closely approximate the value obtained by mathematical calculation using the radius. For the second season samples, an open-tight container with a tube was used. The fruit and another solid heavier than water as sinker (pebbles) were placed into the water slightly without overflowing, the displaced water by the two objects poured into measuring cylinders. The volume of fruit was determined by subtracting the volume of displaced water by the sinker from the volume of displaced water by the fruit and sinker. At the same time the density and specific gravity of watermelon were calculated according to Mohsenin, (1980). The fruit density was obtained by the ratio of weight to volume. The specific gravity was calculated by dividing the fruit weight in air by the weight of displaced water and multiply by the specific gravity of water.

Calculations:

$$\text{Volume}\,(\text{cm}^3) = \frac{\text{Weight of Displaced Water (g)}}{\text{Weight Density of Water (g/cm}^3\text{)}}$$

$$\text{Density}\,(\text{g/cm}^3) = \frac{\text{Weight in Air (g)}}{\text{Volume(cm}^3\text{)}}$$

$$\text{Specific Gravity} = \frac{\text{Weight in Air} \times \text{Specific Gravity of Water}}{\text{Weight of Displaced Water}}$$

3.2.3.2 Shape and Size of Watermelon:

The watermelon shape was approximated by a tri-axial ellipsoid (oblate spheroid and prolate spheroid) and sphere shapes. In the ellipsoid model, the three mutually perpendicular axes (a, b and c) were taken as a measure of size. These dimensions were measured using the projection method as described by Mohsenin (1984) where each sample was placed on the overhead projector plane turned so that its shadow covered the largest area, then the overhead projector was focused to give a sharp boundary. The a and b axes were measured where a is the longest intercept, and b is the longest intercept normal to a. then the sample was turned to obtain a minimum projection area, the a and c axes were measured where the latter is the longest intercept normal to a and b. A ruler was projected along with the fruit image. For a sphere model, the fruit radius, r was based on the average diameter of maximum and minimum values of the measured dimensions, and on the geometric mean diameter according to Mohesnin (1980).

3.2.3.3 Surface Area and Rind Thickness of Watermelon:

The actual surface area of watermelon was determined by a peeling method according to Baten and Marshall (1943). The fruit was peeled in narrow strips. The outlines of the peelings were traced. A digital planimeter was used to determine the total area of the traced strips which was taken as the surface area of watermelon. A mark was put at a point on the circumference of the first drawing, the center of the tracer lens was set to match the starting point. The start key was pressed. The tracer was moved clockwise on the circumference line. After going round, hold key was pressed to stop the measurement temporarily. Then the center of the tracer lens was set to match the starting point on the second drawing. The measurements steps were repeated for all the drawings. At the end the memory key was pressed to end the measurement. For the second and third measurements, the start key was pressed to start and memory key to end the measurement. The average value was obtained after pressing the average key. Inaccuracy associated with the strip thickness was minimized by tracing the peels without the flesh. The rind thickness of the traced strips was measured with a vernier caliper to the nearest 0.1 mm at three different places.

3.2.3.4 Initial Moisture Content of Watermelon Seeds:

The moisture dishes were prepared according to AOAC (1990). Both the dishes and their covers were identified by same number. Before using, the moisture dishes were dried for one hour at the drying temperature (105±1°C) and weighed after being placed in a desiccator until they reached the room temperature. Watermelon seeds were separated from the juice using filter paper. The wet seeds of each watermelon sample were divided into three small samples and kept in polythene bags which carried the number of watermelon sample and the dish number.

Moisture content was determined by the air oven method according to AOAC (1990) where the wet seeds were placed in moisture dishes The covered dishes and their contents were weighed. The weight of each dish was subtracted from the total weight of the dish plus its sample to obtain the wet weight of the sample. The dishes were uncovered and placed with their covers in an air oven at a temperature of 105 $\pm$ 1°C for 48 hours. At the end of the heating period, the dishes were covered as soon as possible and placed in a desiccator. The dishes and the sample were weighed when they reached the room temperature. The percentage of moisture content was calculated by dividing the loss in weight due to heating by the weight of the original sample and multiplied by 100.

Calculation:

$$\%\ \text{Moisture Content, Wet basis} = \frac{(W - W_1)}{W} \times 100$$

Where:

$W \equiv$ Weight of the sample (g)

$W_1 \equiv$ Weight of the sample after drying (g).

3.2.3.5 Specific Gravity of Watermelon Seeds:

The specific gravity of watermelon seeds was determined by the method of pycnometer and toluene ($C_6H_5CH_3$) as described by Mohesnin (1980) where an empty pycnometer was weighed and likewise when filled with distilled water at 20°C. The specific gravity of toluene was determined by dividing the weight of toluene which the bottle held by the weight of the distilled water at the same temperature. The sample was placed in the pycnometer. The bottle was filled with toluene and the temperature was allowed to reach 20°C, then the bottle with its contents was weighed. The specific gravity of seeds was calculated by dividing the weight of seeds in air by the weight of toluene displaced by the seeds (the weight of seeds in air minus the difference in bottle weights when filled with toluene and when containing the seeds) and multiply by the specific gravity of toluene.

Calculation:

- $\text{Specific Gravity of seeds} = \dfrac{\text{Specific Gravity of Toluene} \times \text{Weight of the Seeds}}{\text{Weight of the Toluene displaced by the Seeds}}$

3.2.3.6 Oil Content of Watermelon Seeds:

After determining the initial moisture content, specific gravity of watermelon seeds, the seeds were graded according to the Sudanese specification for watermelon seeds (2005). Weight of the 100 seeds, percentage of the red and brown seeds and percentage of the large seeds were recorded. The percentage of brown and red seeds was determined by dividing their weight by the weight of the whole sample. The length and width for each seed were measured with a vernier caliper. Then the product of seed length × width was determined. The percentage of large seeds has also been determined by dividing the weight of the large seeds by the weight of the whole sample. A well mixed sample was taken for each group of watermelon seeds grade, then it was ground by mortar.

The oil content of watermelon seeds was determined according to the AOAC (1990). Finely ground seeds were extracted by hexane in soxhelt extracting apparatus. The finely ground sample (10g) was accurately weighed in an empty thimble of known weight. The thimble with the material was placed in a soxhelt extractor. A dry and accurately weighed bottom of flask was fitted to the extractor. The hexane was poured in the flask until it filled approximately two thirds of the flask. The flask, the extractor and the condenser were fitted together. Water was allowed to flow through the condenser and heating was continued for 6 hours. The apparatus was carefully dismounted and the solvent in the flask was evaporated to the dryness in an air oven at 105°C for one hour.

Calculation:

$$\% \text{ Oil} = \frac{(W_2 - W_1)}{S} .100$$

Where;

S ≡ Original Weight of the sample (g), W_1 ≡ Weight of empty receiver (g), W_2 ≡ Weight of receiver plus oil (g).

3.2.4 Analysis of Data:

The data were analyzed using the Scientific Package for Social Studies (SPSS, version 12.0). The graphs were presented using the Microsoft Excel 2003.

Chapter Four

Results and Discussion

4.1 Physical Properties of Western Sudan Watermelon:

The determination of the watermelon volume using the platform scale and measuring cylinders techniques yielded identical results but a direct measurement of the volume of the displaced water was obtained by using the second technique so, it was used in determining the watermelon volume for the second season samples.

The average density and specific gravity for the first season samples were 0.762g/cc and 0.765, respectively whereas the second season samples recorded 0.876 g/cc and 0.892. This Variation may be associated with the duration of the rainy season in the localities from which the watermelons were obtained.

For the first season, the relationship between the watermelon volume and the measured dimensions using the multiple linear regression model summarized in Table (4.1). The relationship between the predicted volumes obtained from this model (appendix.1) and the actual volumes (Fig. 4.1) showed that there was a strong correlation between the predicted volumes using the measured dimensions and the actual volumes, with 0.973 R^2 correlation. The second season results showed that the regression model relating the watermelon volume to the measured dimensions was quite varied from the first season model (Table 4.2). This variation may be associated with the number of the replicates and size of the samples tested where the first season samples were 26 small-sized watermelons but the second season samples were 67 watermelons from different size ranges. Also there was strong correlation between the predicted volumes obtained from the regression model (appendix.2) and the actual volumes (Fig. 4.2), with 0.968 R^2 correlations, which reflected a reasonable agreement with the first season result. This finding showed that the estimated volume might be used as a criterion to describe the watermelon shape and the three axial dimensions gave a complete theoretical specification of the watermelon shape.

Table (4.1): Relationship between the watermelon volume and the measured dimensions[1] using the multiple linear regression model[2] for the 2003/04 growing seasons:

Statistics	Axial Dimensions		
	a (mm)	**b (mm)**	**C (mm)**
Mean	66.18	64.05	62.39
Variance	0.492	0.439	0.392
Regression Equation.			V =

[1] a ≡ longest intercept, b ≡ longest intercept normal to a and c ≡ longest intercept normal to a and b.

…. a_n^{bn}, V≡ Volume, a_3^{b3} a_2^{b2} [2] According to Griffith, 1958: V = a_1^{b1}

$a_1, a_2, a_3, \ldots a_n$ ≡ dimensions, $b_1, b_2, b_3, \ldots b_n$=cofficients

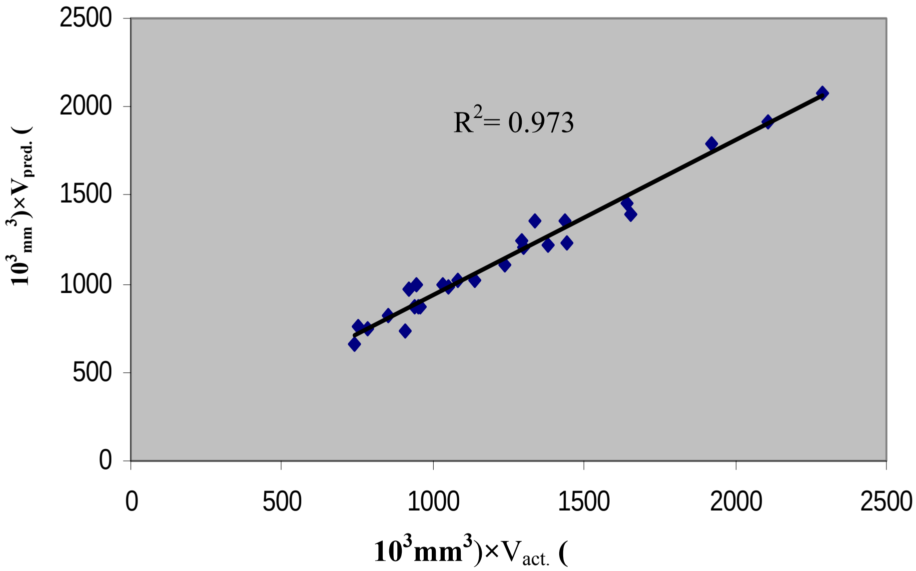


Figure (4.1): Relationship between Predicted Volumes (**$V_{pred.}$**) using Measured Dimensions and Actual Volumes (**$V_{act.}$**) of Watermelon for the 2003/04 Growing Season.

Table (4.2): Relationship between the watermelon volume and the measured dimensions[1] using the multiple linear regression model[2] for the 2004/05 growing seasons:

Statistics	Axial Dimensions		
	a (mm)	b (mm)	C (mm)
Mean	75.03	72.83	71.44
Variance	0.322	0.280	0.254
Regression Equation.			V

[1] a ≡ longest intercept, b ≡ longest intercept normal to a and c ≡ longest intercept normal to a and b .

…. a_n^{bn}**,** V≡ Volume, a_3^{b3} a_2^{b2} 2 According to Griffith, 1958: V = a_1^{b1}

$a_1, a_2, a_3, \ldots a_n$ ≡ dimensions, $b_1, b_2, b_3, \ldots b_n$ = cofficients

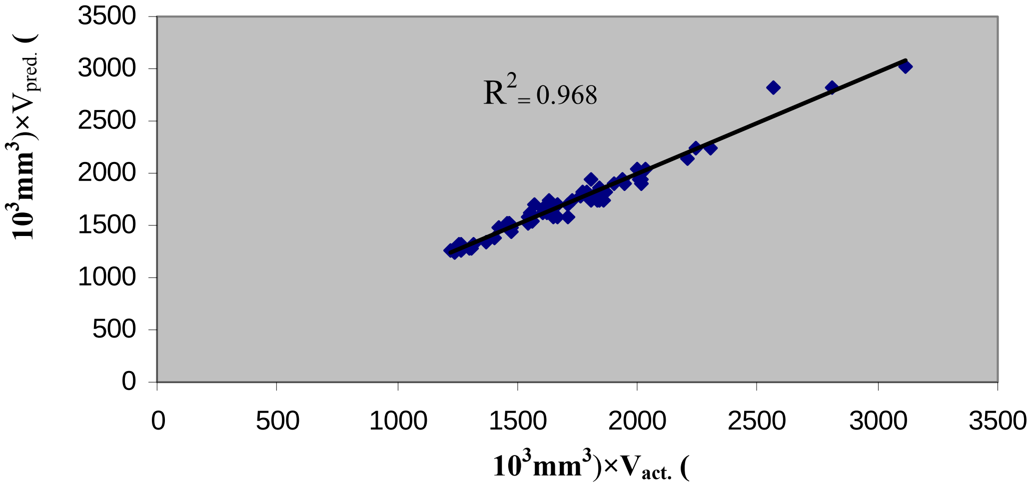


Figure (4.2): Relationship between Predicted Volumes (**$V_{pred.}$**) using Measured Dimensions and Actual Volumes (**$V_{act.}$**) of Watermelon for 2004/05 Growing Season.

Figure (4.3) illustrates the relationship between the predicted volumes using the three geometric shapes models (Appendix .3) and the actual volumes for the first season samples. It was found that the correlations between the predicted volumes using the three models and the actual volumes were generally strong and there was no apparent difference between the three models in predicting the watermelon volume. However, the second season relationships between the predicted volumes using the three models (Appendix.4) and the actual volumes showed that the oblate spheroid model was more strongly related to the actual volume than the sphere and prolate spheroid model (Fig. 4.4), with 0.978 R^2. This finding suggested that the Western Sudan watermelon shape can be described by an oblate spheroid.

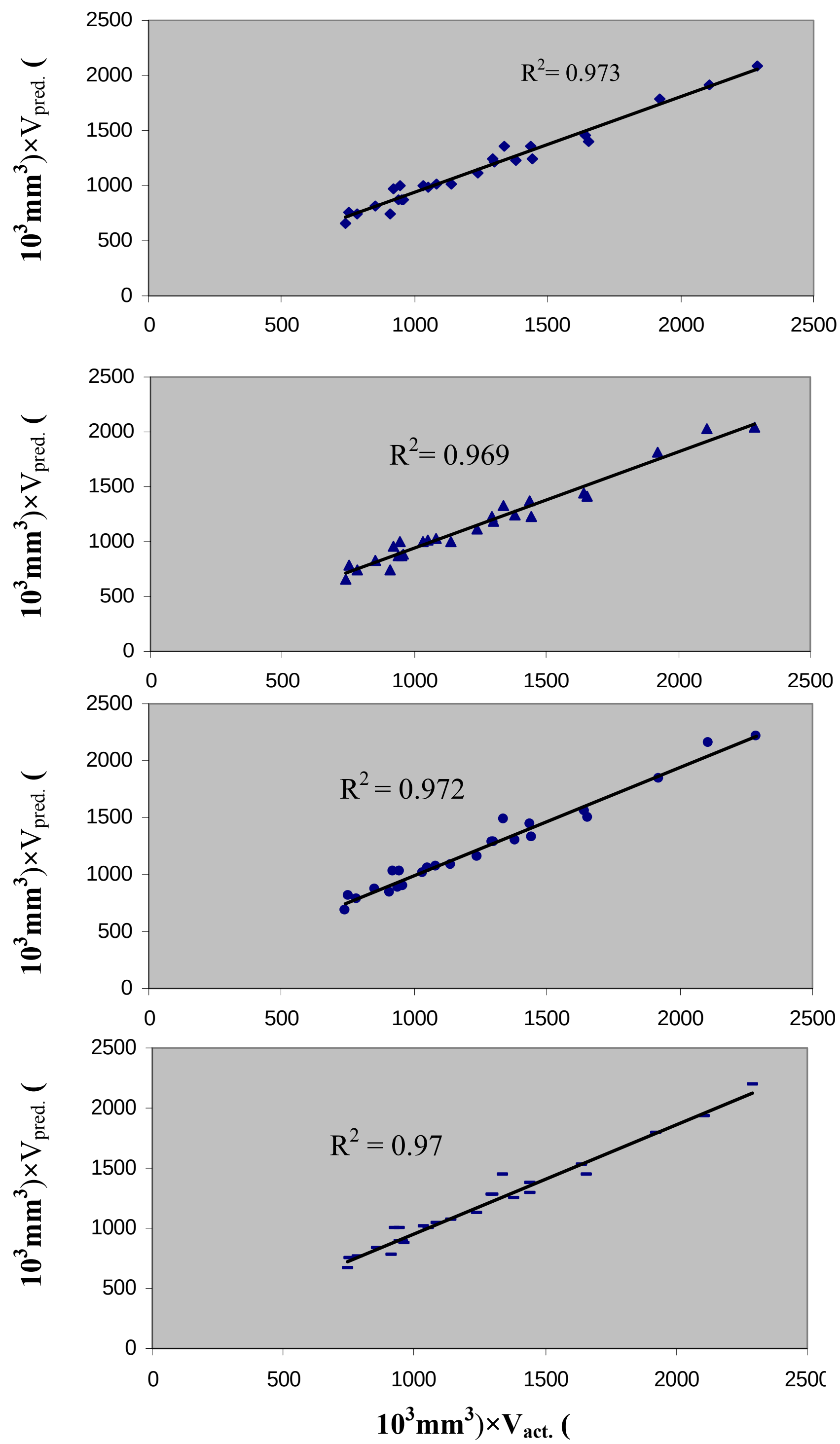


Figure (4.3): Relationships between Predicted Volumes ($V_{pred.}$) and Actual Volumes ($V_{act.}$) of Watermelon. Predictions were made using: Sphere Model based on Geometric Mean Diameter (♦) , Sphere Model based on Average Diameter (▲), Oblate Spheroid Model (*) and Prolate Spheroid Model (▬) for 2003/04 Growing Season.

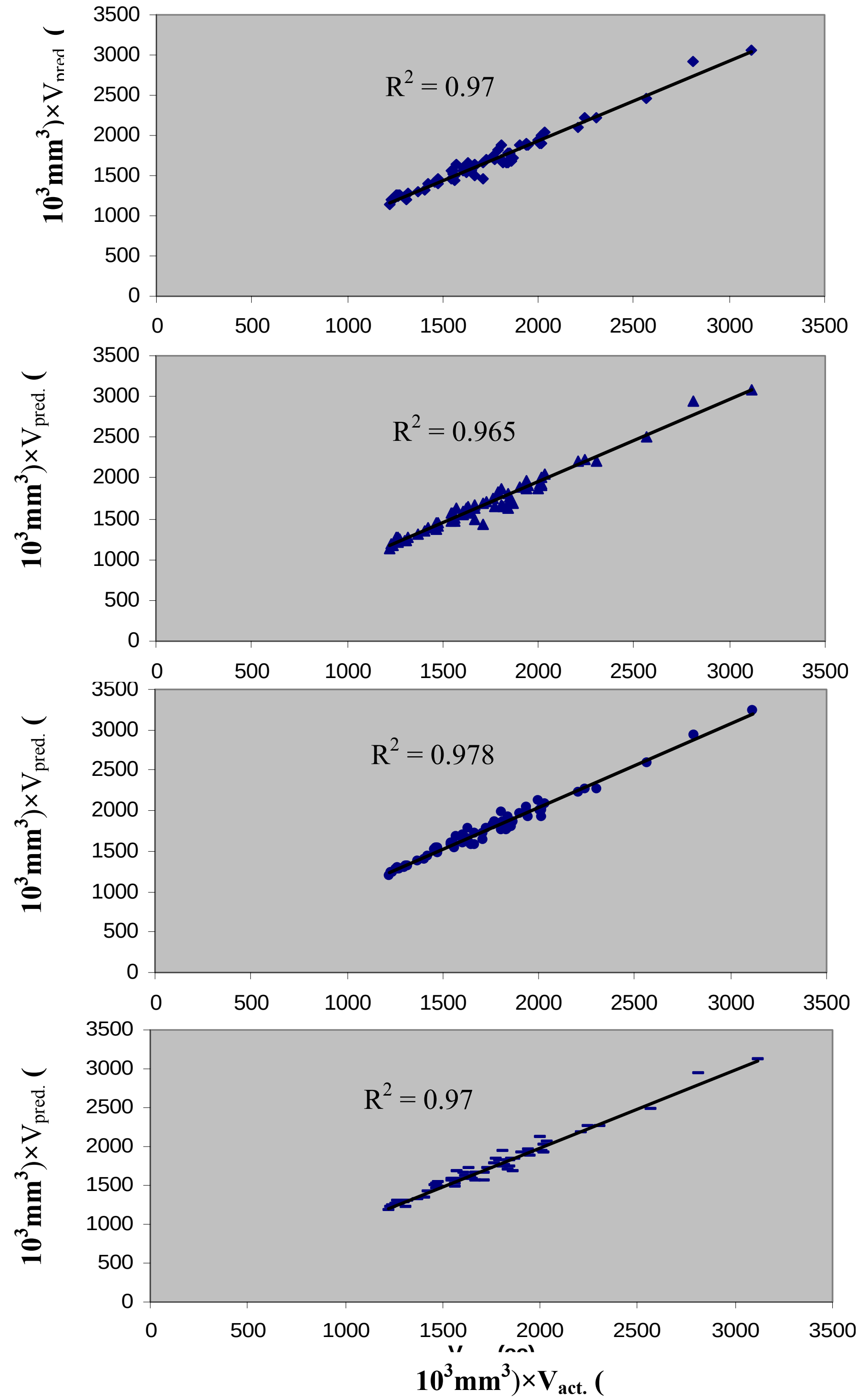


Figure (4.4) Relationships between Predicted Volumes ($V_{pred.}$) and Actual Volumes ($V_{act.}$) of Watermelon. Predictions were made using: Sphere Model based on Geometric Mean Diameter (♦), Sphere Model based on Average Diameter (▲), Oblate Spheroid Model (*) and Prolate Spheroid Model (▬) for 2004/05 Growing Season.

The relationships between the predicted surface areas using the three geometric shapes models (Appendix.5) and the actual surface areas for the second season samples are shown in Figure (4.5). As it has been found before in relating the predicted volumes using the three models to the actual volumes, the three models were generally strong predictors of the watermelon surface area but the second season relationships between the predicted surface areas using the three models (Appendix 6) and the actual surface areas showed that the oblate spheroid model was more strongly correlated with the actual surface area than the sphere and prolate models, with 0.787 R^2 correlation (Fig. 4.6). Hence, the oblate spheroid model was found to be more accurate in predicting both the watermelon volume and surface area. This verified that the watermelon shape can be described by an oblate spheroid.

The average rind thickness was 0.37 mm.

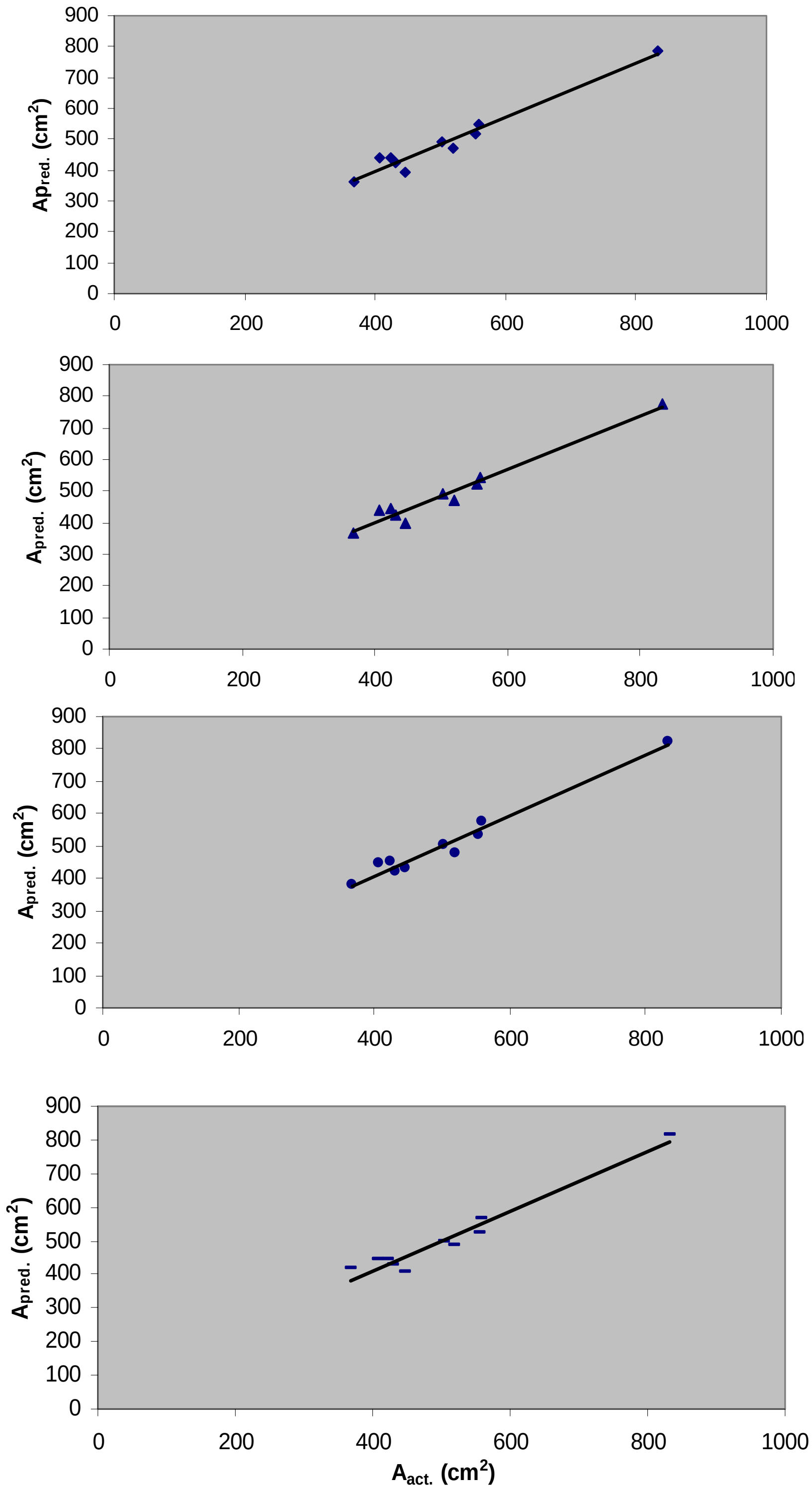


Figure (4.5): Relationships between Predicted Surface Areas ($A_{pred.}$) and Actual Surface Areas ($A_{act.}$) of Watermelon. Predictions were made using: Sphere Model based on Geometric Mean Diameter (♦), Sphere Model based on Average Diameter (▲), Oblate Spheroid Model (*) and Prolate Spheroid Model (▬) for 2003/04 Growing Season.

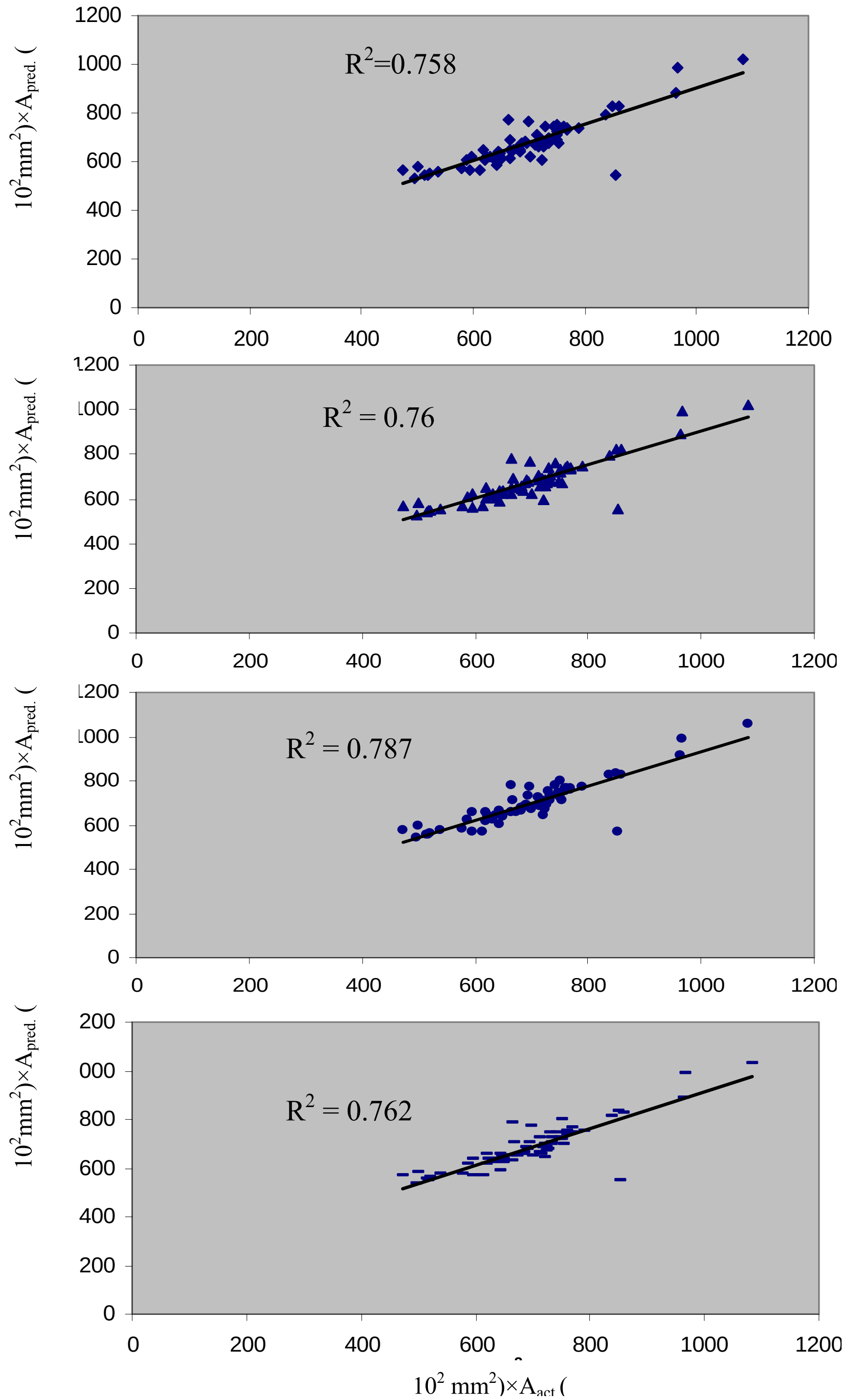


Figure (4.6): Relationships between Predicted Surface Areas ($A_{pred.}$) and Actual Surface Areas ($A_{act.}$) of Watermelon. Predictions were made using: Sphere Model based on Geometric Mean Diameter (♦), Sphere Model based on Average Diameter (▲), Oblate Spheroid Model (*) and Prolate Spheroid Model (▬) for 2004/05 Growing Season.

Table (4.3) summarizes the relationships between the watermelon surface area and its weight by assuming a linear and a non-linear regression models for the first season sample. It was found that the relationship developed between the watermelon surface area and its weight using a linear regression model was stronger than that with a non-linear regression model (Fig. 4.7). The predicted surface areas using a linear and a non-linear regression models (Appendix.7) were related to the actual surface areas, with 0.892 and 0.879 R^2 correlation, respectively (Fig. 4.8). As it can be seen in Table (4.4) and Figure (4.9), the linear regression model was developed to correlate the watermelon surface area to its weight for the second season samples. This result is in conformity with that obtained in the first season, but a linear and non-linear regression models were quite varied from the first season. This variation may be associated with the number of the replicates. The predicted surface areas using a linear and a non – linear regression models (Appendix 8) were related to the actual surface areas, with 0.736 and 0.737R^2correlation, respectively (Fig. 4.10).

Table (4.5) summarizes the relationships between the watermelon surface area and its volume for the first season samples by assuming a linear and a non-linear regression models. As it has found in relating the watermelon surface area to its volume using a linear regression model was stronger than that with a non-linear regression model (Fig. 4.11). The predicted surface areas using a linear and a non-linear regression models (Appendix 8) were related to the actual surface areas, with 0.938 and 0.942 R^2 correlation, respectively (Fig. 4.12). The second season results showed that a linear and a non-linear regression models relating the watermelon surface area to its volume were quite varied from the first season models (Table 4.6), but the linear regression model was developed too to correlate the watermelon surface area to its volume (Fig. 4.13). The predicted surface areas using a linear and a non-linear regression models were related to the actual surface areas, a non-linear regression models were related to the actual surface areas, with 0.775 and 0.773 R^2 correlations, respectively (Fig. 4.14). The results obtained from the two seasons showed that there was strong correlation between the watermelon surface area and its volume (Figures 4.11 and 4.13) than that with its weight (Figures 4.7 and 4.9). Finally, the study revealed that the oblate spheroid model was the most accurate predictor of the watermelon surface area among the models tested.

Table (4.3)

Table (4.3): Relationship between the watermelon surface area and its weight using a linear and a non-linear regression models for the 2003/04 growing season:

Statistics	Linear Regression Model	Non-linear Regression Model[1]
Coef. of Cor. With Actual Area	0.892	0.832
Std. Error of the Estimate	4616.1	-
Linear Regression Equation.		$A = 15191.7+40.6W$
Non-Linear Regression Equation		$A = 478W^{0.689}$

[1] According to Banks (1985): $A = dx^e$, $x \equiv$ weight (gm), A =area (mm^2), $d, e \equiv$ parameters.

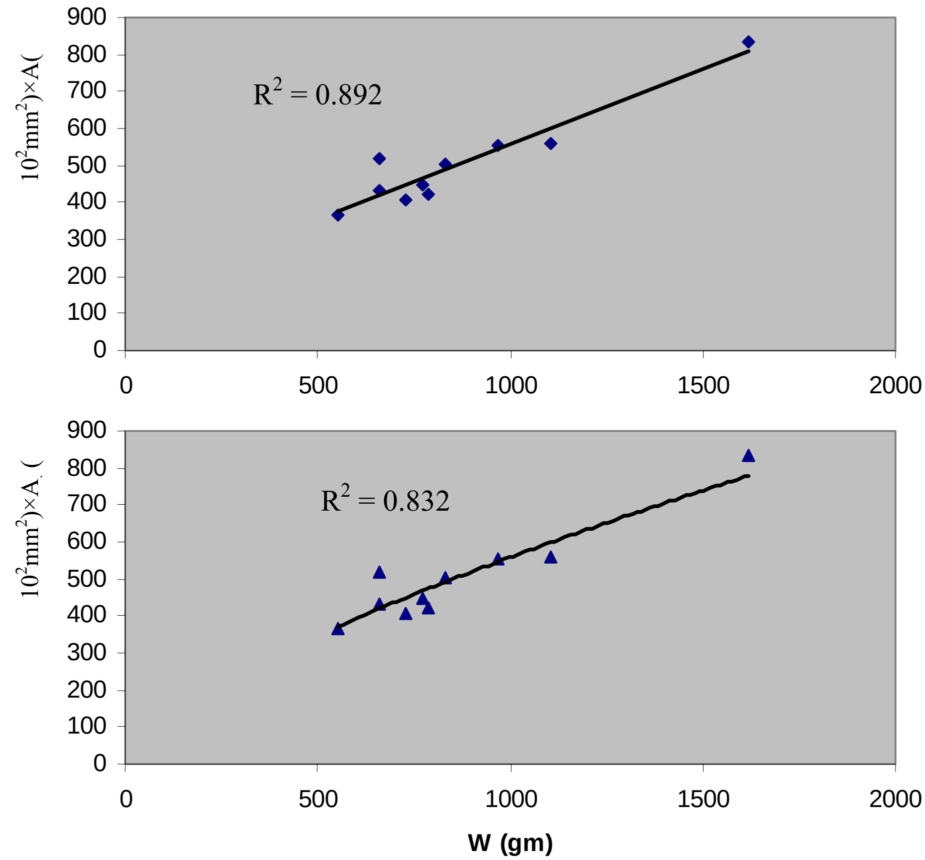


Figure (4.7): Relationships between the Watermelon Surface Area (A) and Its Weight (W) using A Linear Regression Model (♦)and A Non-linear Regression Model (▲) for 2003/04 Growing Season.

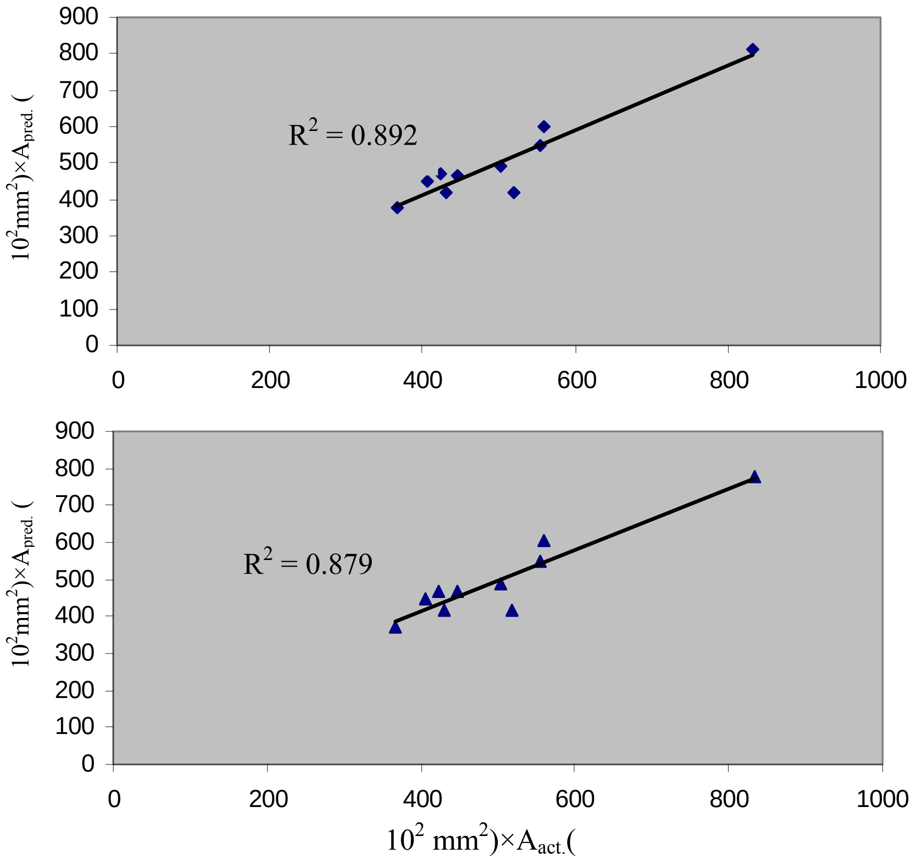


Figure (4.8): Relationships between Predicted Surface Areas ($A_{pred.}$) and Actual Surface Area ($A_{act.}$). Predictions were made using Watermelon Weight based on A Linear Regression Model (♦) and A Non-linear Regression Model (▲), for 2003/04 Growing Season.

Table (4.4): Relationship between the watermelon surface area and its weight using a linear and a non-linear regression models for the 2004/05 growing season:

Parameter and Statistics	Linear Regression Model	Non-linear Regression Model[1]
Coef. of Cor. With Actual Area	0.736	0.699
Std. Error of the Estimate	5670.8	-
Linear Regression Equation.		$A = 25724.9 + 29.3\ W$
Non-Linear Regression Equation		$A = 514W^{0.672}$

[1] According to Banks (1985): $A = dx^e$, $x \equiv$ weight (gm), $A =$ area (mm^2), $d, e \equiv$ parameters.

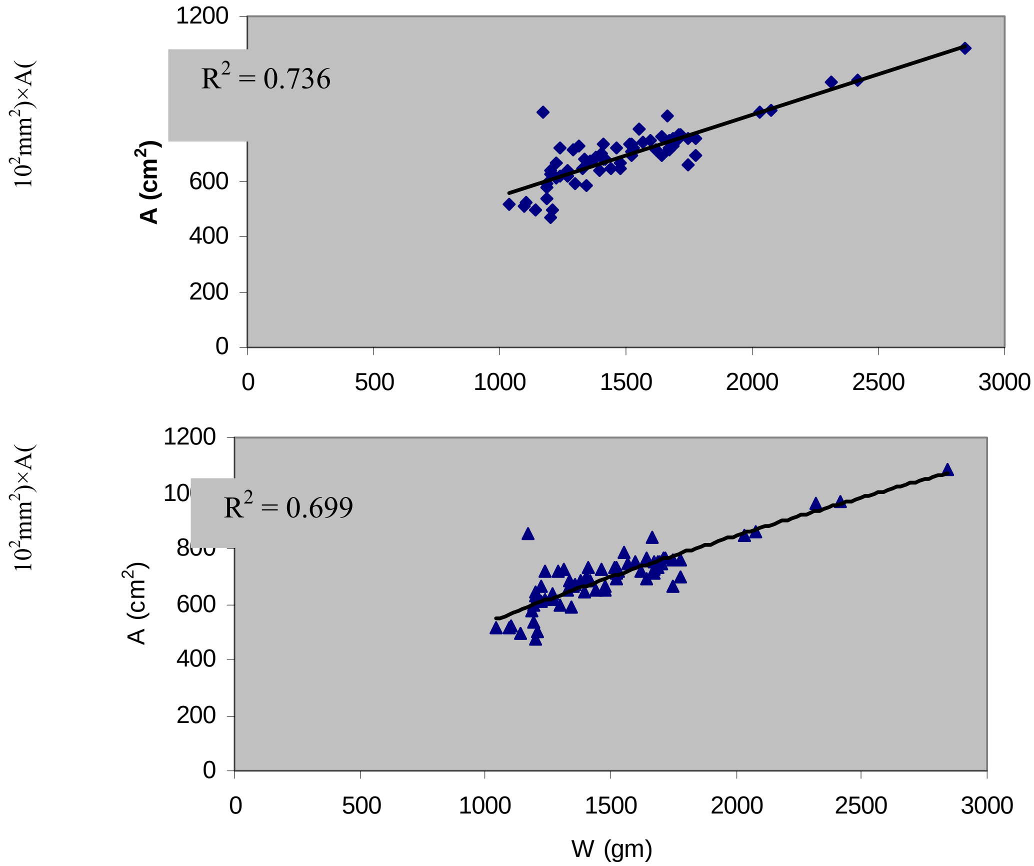


Figure (4.9): Relationships between the Watermelon Surface Area (A) and Its Weight (W) using A Linear Regression Model (♦) and A Non-linear Regression Model (▲) for 2004/05 Growing Season.

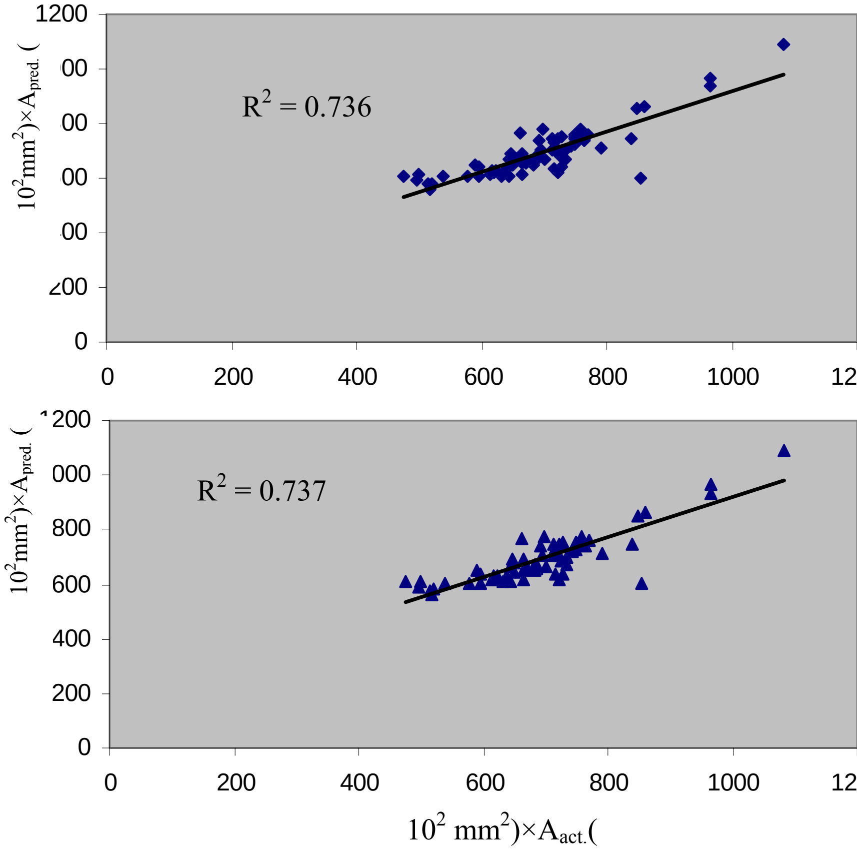
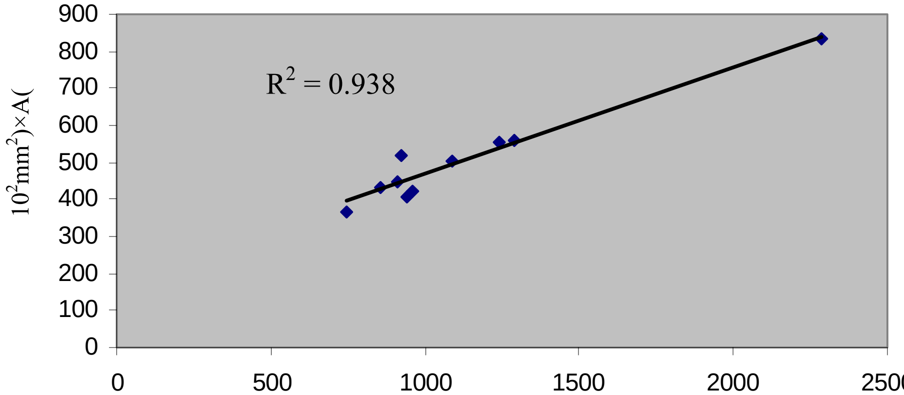


Figure (4.10): Relationships between Predicted Surface Areas ($A_{pred.}$) and Actual Surface Area ($A_{act.}$). Predictions were made using Watermelon Weight based on A Linear Regression Model (♦) and A Non-linear Regression Model (▲) for 2004/05 Growing Season.

Table (4.5): Relationship between the watermelon surface area and its volume using a linear and a non-linear regression models for the 2003/04 growing season:

Statistics	Linear Regression Model	Non-linear Regression Model[1]
Coef. of Cor. With Actual Area	0.938	0.911
Std. Error of the Estimate	3485.2	-
Linear Regression Equation.		$A = 17946.6+28.9V$
Non-Linear Regression Equation		$A_{.} = 372.4V^{0.7}$

[1] According to Banks (1985): $A = dx^{e}$, $x \equiv$ volume (mm^3), A = area (mm^2), $d, e \equiv$ parameters.



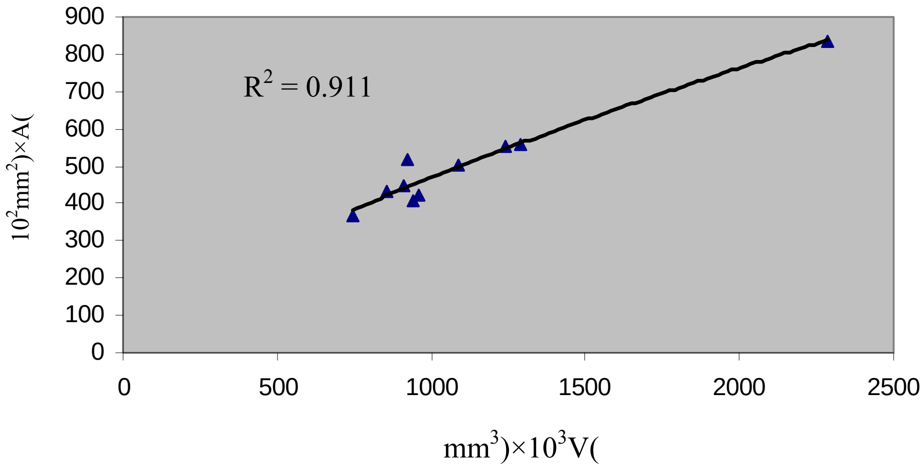


Figure (4.11): Relationships between the Watermelon Surface Area (A) and Its Volume (V) using A Linear Regression Model (♦) and A Non-linear Regression Model (▲) for 2003/04 Growing Season.

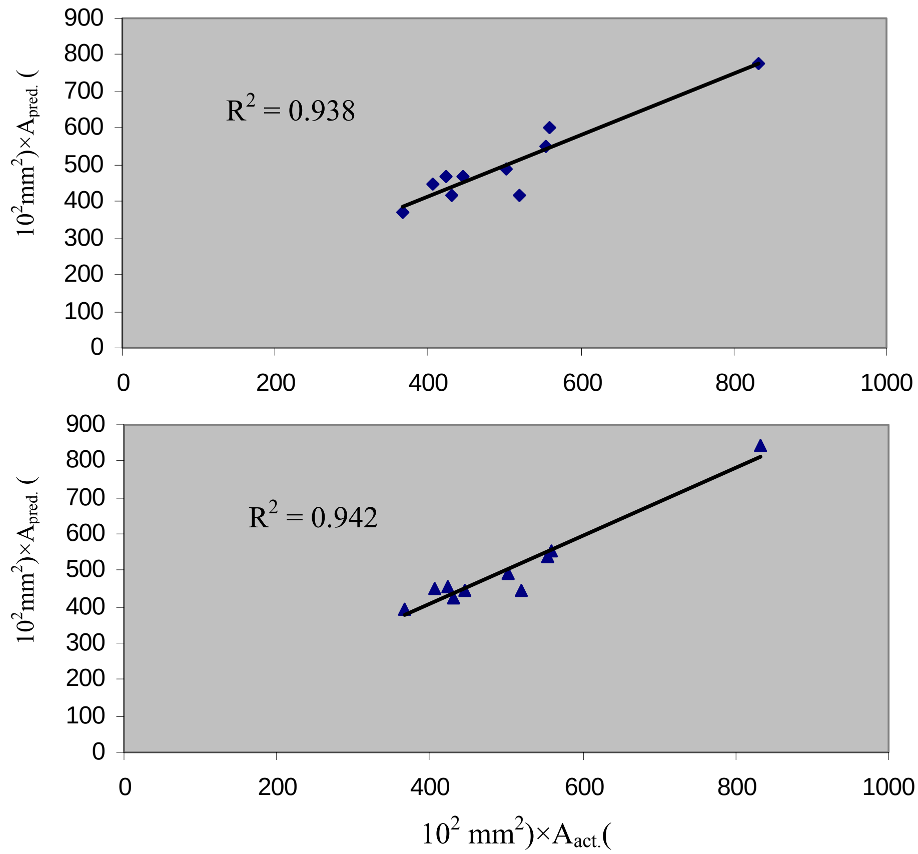


Figure (4.12): Relationships between Predicted Surface Areas ($A_{pred.}$) and Actual Surface Area ($A_{act.}$). Predictions were made using Watermelon Volume based on A Linear Regression Model (♦) and A Non-linear Regression Model (▲) for 2003/04 Growing Season.

Table (4.6): Relationships between the watermelon surface area and its volume using a linear and a non-linear regression models for the 2004/05 growing season:

Statistics	Linear Regression Model	Non-linear Regression Model[1]
Coef. of Cor. With Actual Area	0.775	0.748
Std. Error of the Estimate	5236.4	-
Linear Regression Eq.		$A_{act.} = 23804.2 + 26.7V$
Non-Linear Regression Eq		$A_{act.} = 411.1\ V^{0.689}$

[1] According to Banks (1985): $A = dx^e$, $x \equiv$ volume (mm^3), A = area (mm^2), d, e ≡ parameters.

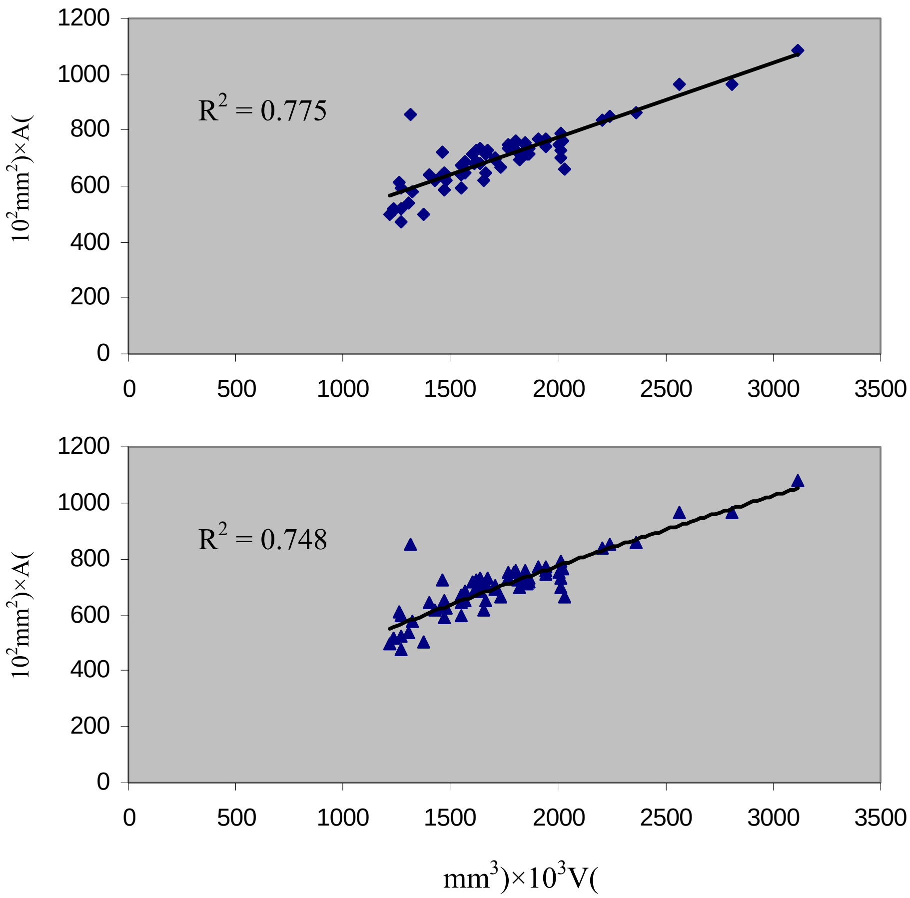


Figure (4.13): Relationships between the Watermelon Surface Area (A) and Its Volume (V) using A Linear Regression Model (♦) and A Non-linear Regression Model (▲) for 2004/05 Growing Season.

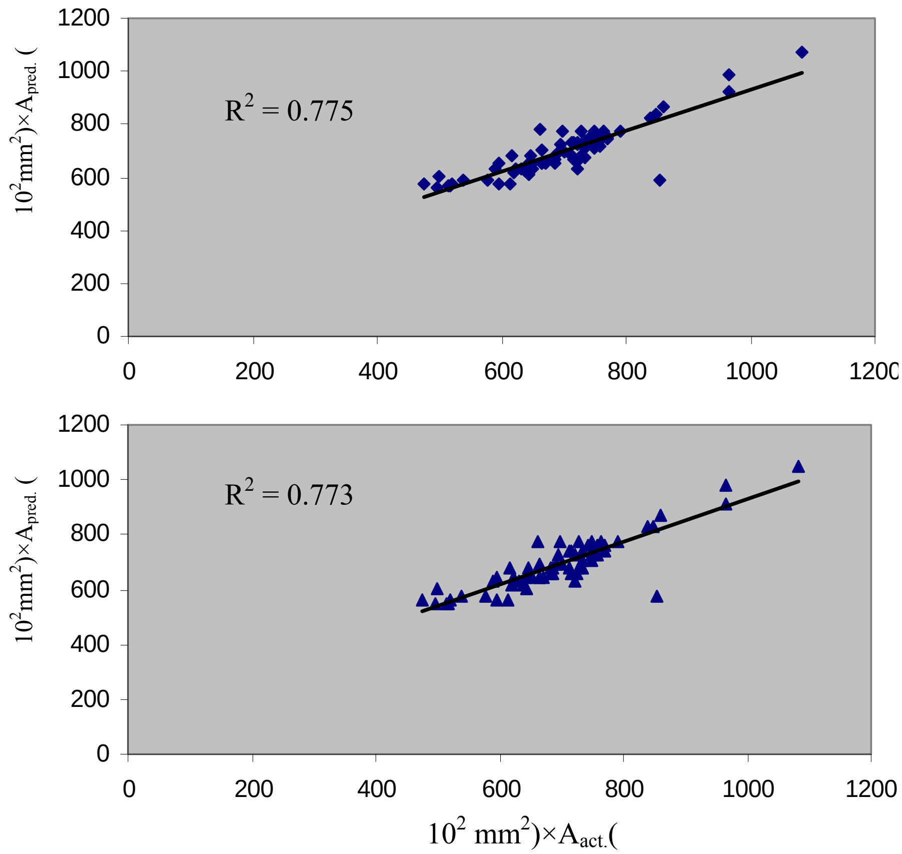


Figure (4.14): Relationships between Predicted Surface Areas ($A_{pred.}$) and Actual Surface Area ($A_{act.}$). Predictions were made using Watermelon Volume based on A Linear Regression Model (♦) and A Non-linear Regression Model (▲) for 2004/05 Growing Season**.**

4.2 Properties of Watermelon Seeds:

In his study, the specific gravity and oil content of watermelon seeds have been found after determining the initial moisture content which has not been studied before. The study revealed that the seeds extracted from Western Sudan watermelon need 48 hrs to be dried at 105$\pm$1°C oven temperature. The average initial moisture content of mature watermelon seeds samples was 38.2% (moisture, w. b.). The average specific gravity of these seeds was 1.016.

Seeds of white variety (white and light yellow seeds) recorded a high weight of 100 seeds, high percentage of large -sized seeds, and a low percentage of red and brown seeds whereas seeds of the variety of Normal Saddir (mixture of white, brown and yellow seeds) recorded high percentage of red seeds. For the white variety, the percentage of red and brown seeds and the percentage of large-sized seeds presented in Table (4.7 a), they were in a reasonable agreement with that reported by Sudanese specification for watermelon seeds (2005). Hence they were graded as Super Casheir, Casheir and Normal white, although the values of weight of 100 seeds were less than the specified ranges. For the seeds of Normal Saddir variety, the weight of 100 seeds, the percentage of large –sized seeds presented in Table (4.7 b), they were within the specification. Hence, the seeds were graded as Farrasha – third.

Table (4.7a) Physical Properties of the seeds of the White variety[1]

Weight of 100 Seeds (gm)	Red and Brown Seeds (%)	Large Seeds [2] (%)
9.481	4.167	95.92
7.84	7.242	81.918
7.408	30.201	71.429

[1] The given values are means

0.5 cm^2) ×[2] The product of length times width is equal or more than (1

The highest oil content was recorded by seeds of the Super Cashier (24.05%) where as the lowest oil content was recorded by seeds of the Farrasha –third (20.05%). These values of oil content (Table 4.8) are in a reasonable agreement with data reported by Mustafa, *et. al*., (1972), Hassan (1998), Saied (2002) and were within the specification of watermelon seeds (2005) in which the watermelon seeds oil ranged from 18 to 28%. Wide range due to the differences which may be associated with the climatic conditions changes and other factors. This considerable amount of oil found in Watermelon seeds qualified them as an excellent source of oil, this is clear when the oil content of watermelon seeds is compared to the oil content of other oil seeds.

Table (4.8): Oil content of two varieties of watermelon seeds:

Variety and Grade	Oil %
White variety	
Super Casheir	24.05
Casheir	22.0
Normal White	22.5
Normal Saddir Variety	
Farrasha- third	20.05

CHAPTER FIVE

CONCLUSIONS

This study has been carried out to determine the most significant physical properties of Western Sudan watermelon (*Citrullus vulgaris*) and watermelon seeds in a form that would have an engineering value. Based on the overall outcomes of the present study, the following conclusions can be drawn:

1. The measurement of the three axial dimensions (a, b and c) would gives a complete theoretical specification of the watermelon shape and size. Oblate spheroid model was the most accurate in predicting watermelon volume and surface area of Western Sudan watermelon among the three models tested. Hence, the shape of Western Sudan watermelon can be described as oblate spheroid.
2. The average density and specific gravity of Western Sudan watermelons were 0.876 g/cc and 0.892, respectively.
3. Linear regression models were developed to correlate watermelon surface area with its weight (A= 25724.9 +29.3W) and volume (A=23804.2 + 26.7V). It was found that the volume was more accurate in predicting watermelon surface area than weight but oblate spheroid model was the most accurate predictor of watermelon surface area among the methods tested.
4. The average initial moisture content of watermelon seeds was 38.2% (moisture, w. b.). Based on this moisture content, the average specific gravity of watermelon seeds was 1.016 and the oil content of watermelon seeds ranged from 20.05 to 24.05%

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Appendix 1: Specifications of the equipment

i. Electronic platform Scale TFW 60[1]

Maximum capacity: 60 kg.

Readability: 59

Resolution: 1: 15.000

Minimum capacity: 100g

Readability (std. Dev.): 5 g

Linearity $\pm$: 10 kg

Units of Measure: kg

Interface: RS- 232 out put optional

Stabilization time: 2 seconds typical

Operating temperature: 0˚C - 40 ̊C

Power supply: 9 V DC from external power supply

Calibration: Automatic External

[1] Adam Equipment Company, 2004

Display: 6 digits LCD digital display

Balance Housing: Indicator ABS plastic Base steel with stainless steel platform.

Pan size: 425 mm × 525 mm

Overall dimensions (w×d×h): 425 mm× 700 mm × 950 mm.

Gross weight: 28 kg.

ii. Digital planimeter KP – 90 N[2]

Liquid Crystal Display: 8 digit.

Measuring range: vertical 325 mm, horizontal 30 mm.

Maximum cumulative Area (scale 1:1): 99999 cm^2, 10 m^2 approx.

Resolution: 0.1 cm when reduced scale 1:1.

Accuracy: within 0.2%.

Power Supply: built-in NiCad rechargeable battery 20 hours operation from each charge.

Recharging Unit Supplied: 15 hours recharge time.

Magnified tracer lens.

Supplied with solid plastic carrying case.

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[2] Placom Co.

iii. **Digital Hotbox Oven (OHF)[3]:**

Temperature range: 30 to 200 ̊C

Temperature fluctuation at 100 ̊C: $\underline{+}1.5$ ($\underline{+}1$).

Time to heat to 200 ̊C (min): 60 (50).

Humidity: MRH 80% up to 31 ̊C decreasing linearly to 50% RH at 40 ̊C.

Altitude: up to 2000 M.

Power rating maximum (watts): 750.

Internal fuse: 13 A

Shelf size (mm): 480 × 400.

No. of shelves supplied: 3.

No. of shelf positions: 6.

Interval between positions (mm): 65.

Working volumes (liters): 97.

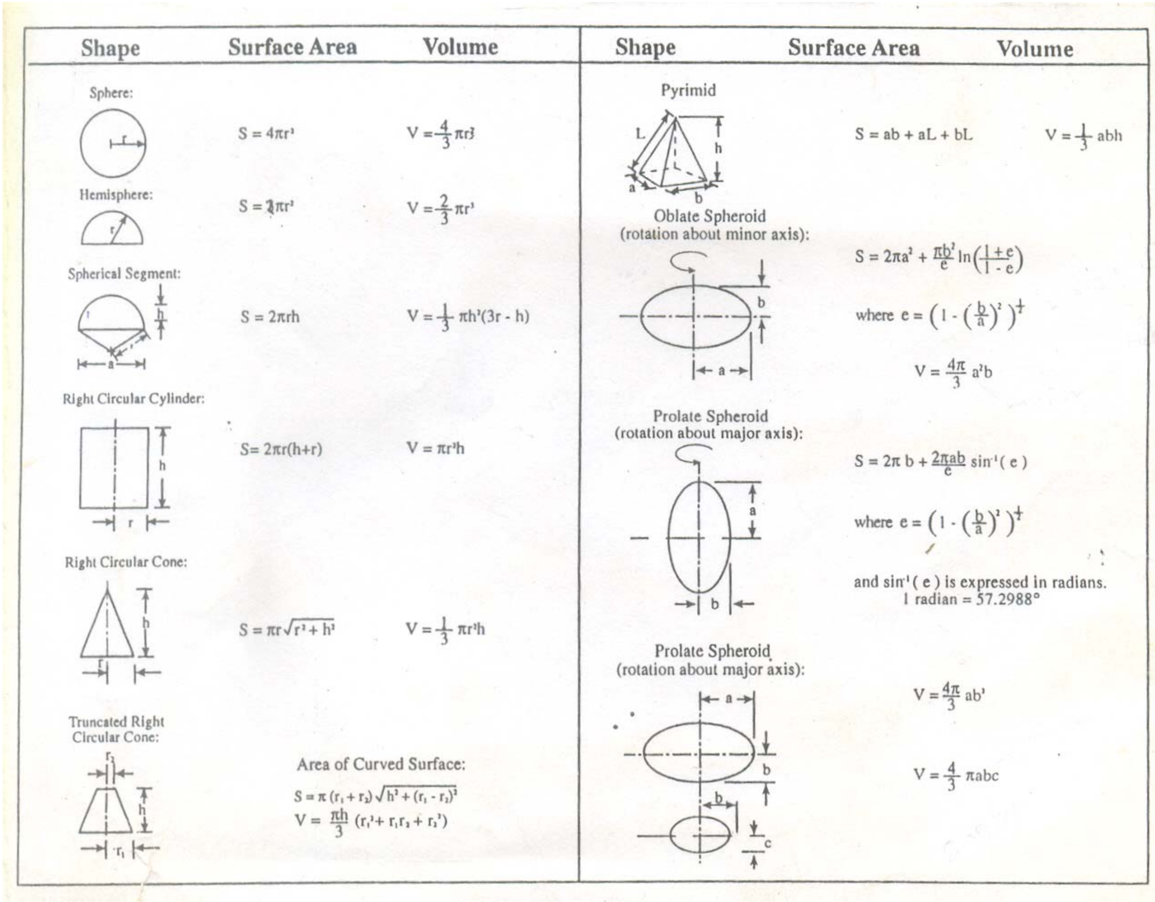
Internal dimensions (H× W × D): 470× 480 ×430.

Overall dimensions (H× W × D): 710 ×590 ×580.

Mass (kg): 28.

[3] Sanyo Gallenkamp PLC.

Appendix 2: Surface Area and Volume Formulas for Various Shapes of *A Geometric Solids



Shape	Surface Area	Volume
Sphere:	$S = 4\pi r^2$	$V = \frac{4}{3}\pi r^3$
Hemisphere:	$S = 3\pi r^2$	$V = \frac{2}{3}\pi r^3$
Spherical Segment:	$S = 2\pi rh$	$V = \frac{1}{3}\pi h^2(3r - h)$
Right Circular Cylinder:	$S = 2\pi r(h+r)$	$V = \pi r^2 h$
Right Circular Cone:	$S = \pi r\sqrt{r^2 + h^2}$	$V = \frac{1}{3}\pi r^2 h$
Truncated Right Circular Cone:	Area of Curved Surface: $S = \pi (r_1 + r_2)\sqrt{h^2 + (r_1 - r_2)^2}$	$V = \frac{\pi h}{3}(r_1^2 + r_1 r_2 + r_2^2)$
Pyrimid	$S = ab + aL + bL$	$V = \frac{1}{3} abh$
Oblate Spheroid (rotation about minor axis):	$S = 2\pi a^2 + \frac{\pi b^2}{e}\ln\left(\frac{1+e}{1-e}\right)$ where $e = \left(1 - \left(\frac{b}{a}\right)^2\right)^{\frac{1}{2}}$	$V = \frac{4\pi}{3} a^2 b$
Prolate Spheroid (rotation about major axis):	$S = 2\pi b + \frac{2\pi ab}{e}\sin^{-1}(e)$ where $e = \left(1 - \left(\frac{b}{a}\right)^2\right)^{\frac{1}{2}}$ and $\sin^{-1}(e)$ is expressed in radians. 1 radian = 57.2988°	
Prolate Spheroid (rotation about major axis):		$V = \frac{4\pi}{3} ab^2$ $V = \frac{4}{3}\pi abc$

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* Engineering Properties of Food and Other Biological Materials, 1998.

Appendix 3: Predicted Volumes ($V_{pred.}$) of Western Sudan Watermelon compared with Actual Volumes ($V_{act.}$) *using the Measured Dimensions for 2003/04 Growing Season

Axial Dimensions a (mm)	b (mm)	c (mm)	103×V_{pred} (mm3)	103×V_{act} (mm3)
55.5	53.6	52.4	707.95	743.00
59.9	55.7	52.8	831.76	910.00
57.6	56.2	54.8	794.33	783.00
59.5	55.0	55.0	812.83	750.00
60.0	57.5	56.5	870.96	853.00
60.0	59.6	58.3	912.01	952.00
60.7	58.7	58.5	912.01	959.00
59.6	59.5	58.8	912.01	940.00
63.2	61.6	59.2	1047.13	923.00
64.1	63.3	59.9	1122.02	1137.00
64.6	60.8	60.0	1071.52	1054.00
64.0	62.2	61.0	1096.48	1085.00
63.2	61.6	61.1	1047.13	945.00
62.4	62.2	61.6	1047.13	1034.00
65.8	63.9	63.0	1174.90	1239.00
67.9	66.9	63.5	1318.26	1298.00
68.7	66.9	64.2	1348.96	1441.00
68.5	65.8	64.7	1318.26	1378.00
71.3	69.7	65.1	1513.56	1339.00
67.5	67.3	65.6	1318.26	1295.00
71.3	67.9	66.6	1445.44	1439.00
72.1	69.1	67.0	1513.56	1654.00
72.1	71.2	67.9	1584.89	1640.00
83.1	74.4	74.1	2137.96	2108.00
77.0	74.5	74.4	1905.46	1921.00
81.1	80.3	76.2	2290.87	2288.00

* According to Griffith (1985): $V = 4.198\ a^{1.596}\ b^{1.316}\ c^{0.104}$, a ≡ longest intercept, b ≡ longest intercept normal to a and c ≡ longest intercept normal to a and b.

Appendix 4: Predicted Volumes ($V_{pred.}$) of Western Sudan Watermelon compared with Actual Volumes ($V_{act.}$) *using the Measured Dimensions for 2004/05 Growing Season

Axial Dimensions			$10^3 \times V_{pred.}$	$10^3 \times V_{act.}$
a (mm)	b (mm)	c (mm)	(mm^3)	(mm^3)
68.5	65.3	63.7	1258.93	1218.00
69.5	64.7	63.8	1288.25	1310.00
66.6	66.5	64.6	1230.27	1236.00
66.9	65.8	65.0	1258.93	1234.00
67.2	67.1	65.1	1258.93	1267.00
68.0	66.7	65.2	1288.25	1304.00
71.6	71.3	66.1	1513.56	1465.00
68.0	67.3	66.2	1318.26	1267.00
67.3	67.1	66.3	1288.25	1271.00
68.4	67.2	66.3	1318.26	1317.00
69.7	67.3	66.4	1348.96	1370.00
74.4	70.8	66.4	1584.89	1710.00
71.7	70.7	66.7	1513.56	1461.00
67.5	67.0	66.8	1318.26	1260.00
70.4	67.5	66.9	1380.38	1401.00
73.7	69.4	67.1	1548.82	1560.00
73.6	70.0	67.7	1513.56	1547.00
71.3	69.2	68.0	1445.44	1471.00
72.1	70.8	68.2	1479.11	1478.00
72.2	69.4	68.5	1513.56	1467.00
70.2	69.7	68.6	1479.11	1426.00
74.2	72.1	68.6	1621.81	1620.00
72.5	71.5	69.1	1584.89	1666.00
72.9	71.8	69.4	1584.89	1553.00
70.9	70.0	69.7	1479.11	1474.00
74.5	73.0	70.4	1659.59	1603.00
75.8	74.0	70.4	1737.80	1845.00
71.8	71.0	70.6	1548.82	1565.00
75.1	72.7	70.8	1698.24	1670.00
75.8	73.7	71.0	1737.80	1632.00
72.5	72.3	71.1	1621.81	1606.00
72.9	71.5	71.2	1584.89	1548.00
72.8	71.8	71.3	1621.81	1556.00
75.9	73.0	71.5	1737.80	1837.00
72.6	71.8	71.6	1584.89	1650.00
73.0	72.9	72.0	1659.59	1618.00
74.1	73.4	72.0	1698.24	1567.00
72.7	72.4	72.1	1621.81	1640.00
75.6	71.5	72.2	1698.24	1666.00
75.0	74.3	72.5	1737.80	1811.00
75.1	72.8	72.8	1698.24	1710.00
76.0	75.7	75.5	1819.70	1790.00
77.8	73.7	68.9	1778.28	1816.00
76.9	75.4	70.0	1819.70	1771.00

76.9	75.5	70.9	1819.70	1868.00
77.1	72.0	71.7	1737.80	1860.00
76.2	73.6	72.0	1737.80	1729.00
78.6	74.3	72.5	1862.09	1846.00
80.0	79.6	72.7	2041.74	2002.00
76.6	74.3	73.0	1778.28	1766.00
76.3	75.7	73.8	1819.70	1852.00
78.5	77.3	74.1	1949.85	1939.00
78.7	76.7	74.3	1949.85	1805.00
78.6	76.2	74.6	1905.46	1907.00
79.3	76.3	74.9	1949.85	2010.00
80.6	75.3	75.0	1949.85	1940.00
79.1	76.2	75.2	1949.85	2018.00
77.8	76.1	76.0	1905.46	1946.00
77.4	76.8	76.4	1905.46	2016.00
81.1	79.7	77.2	2137.96	2205.00
78.7		77.6	1995.26	2015.00
79.7	78.2	77.8	2041.74	2030.00
81.8	78.6	80.1	2238.72	2242.00
81.5	81.2	80.2	2238.72	2306.00
86.6	81.4	82.1	2818.38	2565.00
92.9	82.7	87.6	3019.95	3118.00
89.6	89.5	88.2	2818.38	2810.00
	88.4			

* According to Griffith (1985): $V = 7.311\ a^{1.278}\ b^{1.094}\ c^{0.355}$, a ≡ longest intercept, b ≡ longest intercept normal to a and c ≡ longest intercept normal to a and b.

Appendix 5: Predicted Volumes ($V_{pred.}$) of Western Sudan Watermelon compared with the Actual *using Three Geometric Shapes Models Volumes ($V_{act.}$) for 2003/04 Growing Season.

Axial Dimensions a (mm)	b (mm)	c (mm)	$10^3 \times V_{pred.}$ Sphere Geo. Mean. Dia. (mm^3)	Sphere Aver. Dia. (mm^3)	Oblate Spheroid (mm^3)	Prolate Spheroid (mm^3)	$V_{act.}$ $10^3 \times$ (mm^3)
55.5	53.6	52.4	653.00	658.00	692.00	668.00	743.00
59.9	55.7	52.8	738.00	749.00	837.00	778.00	910.00
57.6	56.2	54.8	743.00	744.00	781.00	762.00	783.00
59.5	55.0	55.0	754.00	786.00	816.00	754.00	750.00
60.0	57.5	56.5	816.00	828.00	867.00	831.00	853.00
60.0	59.6	58.3	873.00	867.00	897.00	893.00	952.00
60.7	58.7	58.5	873.00	887.00	906.00	876.00	959.00
59.6	59.5	58.8	873.00	869.00	885.00	884.00	940.00
63.2	61.6	59.2	965.00	960.00	1031.00	1005.00	923.00
64.1	63.3	59.9	1018.00	998.00	1089.00	1076.00	1137.00
64.6	60.8	60.0	987.00	1013.00	1063.00	1000.00	1054.00
64.0	62.2	61.0	1017.00	1023.00	1067.00	1037.00	1085.00
63.2	61.6	61.1	996.00	1006.00	1031.00	1005.00	945.00
62.4	62.2	61.6	1001.00	998.00	1014.00	1011.00	1034.00
65.8	63.9	63.0	1110.00	1119.00	1159.00	1125.00	1239.00
67.9	66.9	63.5	1208.00	1188.00	1292.00	1273.00	1298.00
68.7	66.9	64.2	1236.00	1229.00	1323.00	1288.00	1441.00
68.5	65.8	64.7	1222.00	1237.00	1293.00	1244.00	1378.00
71.3	69.7	65.1	1355.00	1329.00	1484.00	1451.00	1339.00
67.5	67.3	65.6	1248.00	1235.00	1284.00	1281.00	1295.00
71.3	67.9	66.6	1351.00	1373.00	1446.00	1377.00	1439.00
72.1	69.1	67.0	1398.00	1409.00	1505.00	1442.00	1654.00
72.1	71.2	67.9	1460.00	1437.00	1550.00	1531.00	1640.00
83.1	74.4	74.1	1919.00	2034.00	2152.00	1927.00	2108.00
77.0	74.5	74.4	1788.00	1817.00	1850.00	1790.00	1921.00
81.1	80.3	76.2	2079.00	2038.00	2212.00	2190.00	2288.00

* According to Mohesnin (1980):

For a Sphere: $V = \frac{4}{3}\pi r^3$, r ≡ fruit radius using geometric mean diameter [$(abc)^{1/3}$], average diameter [1/2(a+c)].

For oblate spheroid: $V = \frac{4}{3}\pi a^2 b$

For prolate spheroid: $V = \frac{4}{3}\pi ab^2$

ppendix 6: Predicted Volumes ($V_{pred.}$) of Western Sudan Watermelon compared with the Actual *using Three Geometric Shapes Models Volumes ($V_{act.}$) for 2004/05 Growing Season.

Axial Dimensions			**$10^3 \times V_{pred.}$**				**$V_{act.}$ $10^3 \times$**
a (mm)	**b (mm)**	**c (mm)**	**Sphere**		**Oblate Spheroid (mm^3)**	**Prolate Spheroid (mm^3)**	**(mm^3)**
			Geo. Mean. Dia. (mm^3)	**Aver. Dia. (mm^3)**			
66.6	66.5	64.6	1199.00	1182.00	1236.00	1234.40	1236.00
66.9	65.8	65.0	1199.00	1202.00	1234.00		
67.2	67.1		1232.00	1212.00		1213.00	1234.00
		65.1	1254.00		1269.00		
67.3	67.1	66.3	1265.00	1249.00	1273.00	1267.00	1267.00
67.5	67.0		1249.00	1268.00		1269.00	
		66.8	1258.00	1237.00	1279.00		1271.00
68.0	66.7	65.2	1277.00		1304.00	1269.00	
68.0	67.3		1145.00	1265.00			1260.00
		66.2	1204.00	1280.00	1292.00	1290.00	
68.4	67.2	66.3	1306.00	1137.00	1317.00		1304.00
68.5	65.3		1406.00			1292.00	
		63.7	1329.00	1240.00	1184.00		1267.00
69.5	64.7	63.8	1449.00	1320.00	1309.00	1294.00	
69.7	67.3		1406.00	1400.00			1317.00
		66.4	1413.00		1370.00	1175.00	
70.2	69.7	68.6	1416.00	1355.00	1439.00		1218.00
70.4	67.5		1508.00	1455.00		1216.00	
		66.9	1459.00	1415.00	1401.00		1310.00
70.9	70.0	69.7	1438.00		1474.00	1322.00	
71.3	69.2		1500.00	1367.00			1370.00
		68.0	1561.00	1388.00	1474.00	1429.00	
71.6	71.3	66.1	1563.00	1512.00	1531.00		1426.00
71.7	70.7		1590.00			1344.00	
		66.7	1561.00	1446.00	1522.00		1401.00
71.8	71.0	70.6	1555.00	1458.00	1533.00	1474.00	
72.1	70.8		1522.00	1487.00			1474.00
		68.2	1605.00		1542.00	1474.00	
72.2	69.4	68.5	1464.00	1550.00	1515.00		1471.00
72.5	71.5		1438.00	1570.00		1525.00	
		69.1	1640.00	1590.00	1574.00		1465.00
72.5	72.3	71.1	1537.00		1592.00	1501.00	
72.6	71.8		1465.00	1567.00			1461.00
		71.6	1604.00	1567.00	1585.00	1516.00	
72.7	72.4	72.1	1692.00	1509.00	1603.00		1565.00

72.8	71.8		1619.00			1542.00	
		71.3	1667.00	1596.00	1594.00		1478.00
72.9	71.5	71.2	1635.00	1477.00	1592.00	1457.00	
72.9	71.8		1661.00	1462.00			1467.00
		69.4	1654.00		1598.00	1553.00	
73.0	72.9	72.0	1659.00	1633.00	1627.00		1666.00
73.6	70.0		1819.00	1640.00		1587.00	
		67.7	1691.00	1426.00	1588.00		1606.00
73.7	69.4	67.1	1786.00		1579.00	1585.00	
74.1	73.4		1740.00	1593.00			1650.00
		72.0	1700.00	1680.00	1688.00	1596.00	
74.2	72.1	68.6	1724.00	1626.00	1663.00	1572.00	1640.00
74.4	70.8		1676.00	1694.00			
		66.4	1902.00	1667.00	1642.00	1561.00	1556.00
74.5	73.0	70.4	1655.00		1697.00		
75.0	74.3		1885.00	1656.00		1574.00	1548.00
75.1		72.5	1883.00	1636.00	1751.00		
	72.7	70.8	1774.00	1646.00	1718.00	1625.00	1553.00
75.1	72.8		1872.00				
75.6		72.8	1879.00	1821.00	1719.90	1588.00	1618.00
	71.5	72.2	2000.00	1704.00	1712.00		
75.8	73.7		1899.00	1771.00		1487.00	1547.00
75.8		71.0	1898.00		1774.00		
	74.0	70.4	2041.00	1753.00	1781.00	1672.00	1560.00
75.9	73.0		1939.00	1660.00			
76.0		71.5	1907.00	1691.00	1762.00	1616.00	1567.00
	75.7	75.5	2229.00		1832.00		
76.2	73.6		2108.00	1725.00		1562.00	1620.00
76.3		72.0	2229.00	1905.00	1790.00		
	75.7	73.8	2926.00	1653.00	1846.00	1663.00	1710.00
76.6	74.3		3051.00			1734.00	
76.9		73.0	2463.00	1905.00	1826.00		1603.00
	75.4	70.0		1861.00	1868.00	1663.00	
76.9	75.5			1806.00			1811.00
77.1		70.9			1870.00	1667.00	
	72.0	71.7		1883.00	1793.00		1670.00
77.4	76.8			1875.00		1651.00	
77.8		76.4		1999.00	1927.00		1710.00
	73.7	68.9			1869.00	1725.00	
77.8	76.1			1924.00			1666.00
78.5		76.0		1920.00	1929.00	1739.00	
	77.3	74.1		2046.00	1995.00		1632.00
78.6	74.3					1694.00	
78.6		72.5		1864.00	1923.00		1845.00

	76.2	74.6	1973.00	1972.00	1824.00	
78.7	76.7		2214.00			1837.00
78.7		74.3		1990.00	1729.00	
	78.2	77.6	2206.00	2029.00		1790.00
79.1	76.2		2222.00		1831.00	
79.3		75.2	2943.00	1997.00		1729.00
	76.3	74.9		2010.00	1771.00	
79.7	78.6		3079.00			1852.00
80.0		77.8	2514.00	2091.00	1831.00	
	79.6	72.7		2134.00		1766.00
80.6	75.3				1836.00	
81.5		75.0		2049.00		1771.00
	81.4	80.2		2265.00	1674.00	
81.8	79.7					1868.00
81.8		77.2		2234.00	1912.00	
	81.2	80.1		2276.00		1860.00
89.6	88.4				1770.00	
92.9		88.2		2930.00		2016.00
	89.5	87.6		3236.00	1887.00	
86.6	82.7					1816.00
		82.1		2598.00	1965.00	
						1946.00
					1818.00	
						1939.00
					1912.00	
						1846.00
					1939.00	
						1907.00
					2016.00	
						1805.00
					1924.00	
						2015.00
					1934.00	
						2018.00
					2062.00	
						2010.00
					2123.00	
						2030.00
					1914.00	
						2002.00
					2262.00	
						1940.00
					2176.00	
						2306.00

2259.00	
	2205.00
2933.00	
	2242.00
3117.00	
	2810.00
2481.00	
	3118.00
	2565.00

[*] According to Mohesnin (1980):

For a Sphere: $V = \frac{4}{3}\pi r^3$, r ≡ fruit radius using geometric mean diameter [$(abc)^{1/3}$], average diameter [1/2(a+c)].

For oblate spheroid: $V = \frac{4}{3}\pi a^2 b$

For prolate spheroid: $V = \frac{4}{3}\pi a b^2$

Appendix 7: Predicted Surface Areas ($A_{pred.}$) of Western Sudan Watermelon using Three Geometric Shapes Models* compared with the Actual Areas ($A_{act.}$) for 2003/04 Growing Season.

Axial Dimensions			$10^2\times A_{pred.}$				$A_{act.}$
a (mm)	b (mm)	c (mm)	Sphere		Oblate Spheroid (mm^2)	Prolate Spheroid (mm^2)	$10^2\times$ (mm^2)
			Geo. Mean. Dia. (mm^2)	Aver. Dia. (mm^2)			
59.9	55.7	52.8	394.90	399.00	429.90	409.50	446.70
60.0	57.5	56.5	422.50	426.40	421.20	427.30	430.30
	58.7	58.5	441.80	446.40	452.50	442.50	422.90
60.7	61.6	59.2	472.40	470.70	480.50	485.10	519.50
63.2	62.2	61.0	489.10	490.90	504.50	496.10	503.00
	59.5		441.90	439.70	445.50	445.00	406.80
64.0	53.7	58.8	364.40	365.80	378.50	416.20	367.70
59.6	66.9	52.4	548.60	542.40	573.70	568.00	559.20
	63.9		518.30	521.20	533.20	522.80	554.90
55.5	80.3	63.5	787.30	777.30	821.40	816.00	832.80
67.9		63.0					
65.8		76.2					
81.1							

* * According to Mohesnin (1980):

For a Sphere: $A = 4\pi r^2$, r ≡ fruit radius using geometric mean diameter [$(abc)^{1/3}$], average diameter [1/2(a+c)].

For oblate spheroid: $A = 2\pi a^2 + \frac{\pi b2}{e}\ln\frac{1+e}{1-e}$, e ≡ eccentricity = [$(1-(b/a)^2)^{1/2}$].

For prolate spheroid: $A = 2\pi b^{2} + \frac{2\pi ab}{e}\sin^{-1} e$

Appendix 8: Predicted Surface Areas ($A_{pred.}$) of Western Sudan Watermelon` using Three Geometric Shapes Models *compared with the Actual Areas ($A_{act.}$) for 2004/05 Growing Season.

Axial Dimensions			**$10^2 \times A_{pred.}$**				**$A_{act.}$ $10^2\times$**
a (mm)	**b (mm)**	**c (mm)**	**Sphere**		**Oblate Spheroid (mm^2)**	**Prolate Spheroid (mm^2)**	**(mm^2)**
			Geo. Mean. Dia. (mm^2)	**Aver. Dia. (mm^2)**			
66.6	66.5	64.6	545.60	540.80	555.70	555.20	513.40
66.9	65.8	65.0	545.70	546.60	555.70	549.50	
			555.00	549.90	564.50	564.00	518.30
6.72	67.1	65.1	562.40	560.70	568.20	567.10	
67.3	67.1	66.3	565.80	568.30	570.90		521.80
			563.50	565.80	573.10	568.10	
67.5	67.0	66.8	561.10	557.40	577.30	567.20	594.50
68.0	66.7	66.2	569.10	570.00	581.80	573.10	
	67.3		529.70	526.90	541.40	574.20	613.00
68.0	67.2	65.2	546.60	558.20	572.60		
68.4	65.3	66.3	577.40	581.10	596.70	538.70	473.80
			606.90	605.20	616.70	552.40	
68.5	64.7	63.7	585.30	592.20	605.80	582.90	537.50
69.5	67.3	63.8	619.20	621.00	626.00	613.80	
			606.80	609.60	626.20		578.70
69.7	69.7	66.4	609.10	595.60	644.00	589.10	
70.2	67.5	68.6	609.90	601.80	640.80	620.70	496.40
			635.20	637.00	642.70	613.90	
70.4	70.0	66.9	621.90	618.40	645.50	642.20	854.20
70.9	69.2	69.7	616.00	621.90	638.00		
			633.80	629.90	653.50	634.90	499.60
71.3	71.3	68.0	650.80	647.80	679.20	638.20	
71.6	70.7	66.1	651.40	653.30	657.60	637.70	619.90
			658.70	658.70	661.40	621.60	
71.7	71.0	66.7	650.80	652.30	660.30		642.70
71.8	70.8	70.6	649.00	652.30	659.40	647.50	
			639.80	636.20	661.20	659.10	630.50
72.1	69.4	68.2	662.90	660.50	671.10	655.60	

* * According to Mohesnin (1980):

For a Sphere: $A = 4\pi r^2$, $r \equiv$ fruit radius using geometric mean diameter $[(abc)^{1/3}]$, average diameter $[1/2(a+c)]$.

For oblate spheroid: $A = 2\pi a^2 + \frac{\pi b2}{e}\ln\frac{1+e}{1-e}$, $e \equiv$ eccentricity $= [(1-(b/a)^2)^{1/2}]$.

For prolate spheroid: $A = 2\pi b^{2} + \frac{2\pi ab}{e}\sin^{-1} e$

72.2	71.5	68.5	622.70	627.20	658.60	660.50	588.00
			616.00	622.80	655.80		
72.5	72.3	69.1	672.60	670.60	686.00	654.20	721.50
72.5	71.8	71.1	644.10	640.60	679.20	650.90	
			623.80	622.80	673.60	654.60	638.90
72.6	72.4	71.6	686.80	683.50	703.30	670.50	
72.7	71.8	72.1	666.80	668.70	693.40		649.10
			680.00	687.20	693.80	636.90	
72.8	71.5	71.3	672.10	686.30	692.20	630.00	623.50
72.9	71.8	71.2	678.40	677.00	708.60	681.70	
			676.40	671.50	710.00	666.30	650.00
72.9	72.9	69.4	677.80	682.60	705.30		
73.0	70.0	72.0	720.70	721.10	723.00	651.70	647.80
			686.50	690.00	713.10	698.90	
73.6	69.4	67.7	711.80	707.80	728.20	678.80	682.60
73.7	73.4	67.1	699.70	703.10	722.90	679.50	
			688.90	677.90	732.70		618.00
74.1	72.1	72.0	695.40	686.30	734.00	667.00	
74.2	70.8	68.6	680.00	695.60	714.00	695.20	682.00
			742.50	743.10	749.80	698.00	
74.4	74.3	66.4	676.60	676.10	734.40	687.20	664.90
75.0	72.7	72.5	737.90	743.10	749.40		
			737.50	731.60	766.90	721.10	671.90
75.1	72.8	70.8	708.60	717.30	748.40	703.80	
75.1	71.5	72.8	734.40	737.30	760.90	724.40	643.50
			736.30	735.40	765.20	708.40	
75.6	73.7	72.2	767.80	767.50	773.50		725.30
75.8	74.0	71.0	741.50	748.00	767.20	723.10	
	73.0		740.40	747.00	771.00	725.10	595.60
75.8		70.4	662.60	659.60	687.50	682.10	
75.9	75.7	71.5	772.90	779.30	778.90	745.90	665.10
	73.6		752.00	732.50	801.10		
76.0		75.5	743.60	760.60	780.40	708.40	687.10
76.2	75.7	72.0	825.10	821.40	830.00	738.40	
	74.3		795.10	794.20	826.70	765.00	685.20
76.3		73.8	825.10	823.50	836.40	720.90	
76.6	75.4	73.0	882.00	894.10	913.80		700.90
	75.5		989.40	993.10	986.80	745.00	
76.9		70.0	1017.30		1056.40	752.20	721.80
76.9	72.0	70.9		1023.50		771.70	
	76.8					748.70	727.40
77.1		71.7					
77.4	73.7	76.4				751.50	692.30
	76.1					659.40	

77.8		68.9	783.20	711.40
77.8	77.3	76.0	798.90	
	74.3			734.00
78.5		74.1	746.20	
78.6	76.2	72.5	829.30	754.30
	76.7		812.50	
78.6		74.6	832.30	723.00
78.7	78.2	74.3		
	76.2		886.20	750.30
78.7		77.6	991.30	
79.1	76.3	75.2	1030.30	666.00
	73.0			
79.3		74.9		712.60
79.5	78.6	70.4		
	79.6			733.50
79.7		77.8		
80.0	75.3	72.7		748.90
	81.4			
80.6		75.0		733.60
81.5	79.7	80.2		
	81.2			717.10
81.8		77.2		
81.8	82.7	80.1		729.30
	88.4			
86.6		82.1		694.80
89.6	89.5	88.2		
				759.00
92.9		87.6		
				769.30
				749.60
				769.20
				758.80
				698.00
				763.20
				789.50
				715.50

663.00
750.10
743.30
859.80
838.10
849.20
964.00
966.70
1082.10

Appendix 9: Predicted Surface Areas ($A_{pred.}$) Using A Linear and A Non-based on Watermelon Weight compared with *Linear Regression Models Actual Surface Areas ($A_{act.}$) for 2003/04 Season

W (gm)	**$10^2 \times A_{pred.}$** Linear Reg. Model (mm^2)	Non – Linear Reg. Model (mm^2)	**$10^2 \times A_{act.}$** (mm^2)
775.00	442.46	467.74	446.70
660.00	425.98	416.87	430.30
785.00	456.62	467.74	422.90
660.00	446.21	416.87	519.50
830.00	493.03	489.78	503.00
730.00	451.13	446.68	406.80
555.00	394.19	371.54	367.70
1105.00	552.57	602.56	559.20
970.00	537.54	549.54	554.90
1620.00	840.70	776.25	832.80

* * For a linear regression model: $A = 15191.7 + 40.6W$
a non-linear regression Model according to Banks (1985): $A = 478W^{0.689}$

Appendix 10: Predicted Surface Areas ($A_{pred.}$) Using A Linear and A based on Watermelon Weight compared *Non-Linear Regression Models with Actual Surface Areas ($A_{act.}$) for 2004/05 Season

W **(gm)**	**$10^2 \times A_{pred.}$** **Linear Reg. Model (mm^2)**	**Non – Linear Reg. Model (mm^2)**	**$10^2 \times A_{act}$** **mm^2)(**
1140.00	591.27	588.84	496.40
1200.00	608.85	602.56	642.70
1170.00	600.06	588.84	854.20
1095.00	578.08	562.34	513.40
1190.00	605.92	602.56	594.50
1040.00	561.97	549.54	518.30
1190.00	605.92	602.56	537.50
1185.00	604.45	602.56	578.70
1210.00	611.78	602.56	499.60
1105.00	581.01	575.44	521.80
1200.00	608.85	602.56	630.50
1345.00	651.33	645.65	588.00
1270.00	629.36	630.96	623.50
1300.00	638.15	630.96	595.60
1200.00	608.85	602.56	473.80
1410.00	670.38	676.08	682.00
1225.00	616.17	616.60	613.00
1240.00	620.57	616.60	619.90
1360.00	655.73	660.69	671.90
1330.00	646.94	645.65	650.00
1240.00	620.57	616.60	721.50

* * For a linear regression model: $A = 25724.9 + 29.3W$
a non-linear regression Model according to Banks (1985): $A = 514W^{0.672}$

1270.00	629.36	630.96	638.90
1670.00	746.56	758.58	749.60
1440.00	679.17	676.08	649.10
1525.00	704.07	707.95	711.40
1670.00	746.56	758.58	712.60
1530.00	705.54	707.95	721.80
1395.00	665.98	660.69	643.50
1380.00	661.59	660.69	687.10
1475.00	689.42	691.83	647.80
1675.00	748.02	758.58	723.00
1520.00	702.61	707.95	733.60
1640.00	737.77	741.31	692.30
1225.00	616.17	616.60	664.90
1420.00	673.31	676.08	685.20
1745.00	768.53	776.25	759.00
1460.00	685.03	691.83	725.30
1515.00	701.14	707.95	733.50
1745.00	768.53	776.25	663.00
1685.00	750.95	758.58	754.30
1400.00	667.45	676.08	700.90
1555.00	712.86	724.44	789.50
1265.00	627.89	630.96	618.00
1595.00	724.58	724.44	750.30
1710.00	758.28	758.58	769.20
1645.00	739.23	741.31	763.20
1695.00	753.88	758.58	750.10
1525.00	704.07	707.95	694.80
1350.00	652.80	645.65	665.10
2030.00	852.04	851.14	849.20

1720.00	761.21	776.25	769.30
1410.00	670.38	676.08	734.00
1475.00	689.42	691.83	666.00
1310.00	641.08	645.65	727.40
1570.00	717.26	724.44	743.30
1775.00	777.32	776.25	698.00
1335.00	648.40	645.65	682.60
1290.00	635.22	630.96	715.50
1620.00	731.91	741.31	717.10
1775.00	777.32	776.25	758.80
1685.00	750.95	758.58	729.30
2840.00	1089.37	1071.52	1082.10
2415.00	964.84	954.99	966.70
1665.00	745.09	758.58	838.10
2075.00	865.22	870.96	859.80
2315.00	935.54	933.25	964.00
1705.00	756.81	758.58	748.90

Appendix 11: Predicted Surface Areas ($A_{pred.}$) Using A Linear and A based on Watermelon Volume compared *Non-Linear Regression Models with Actual Surface Areas ($A_{act.}$) for 2003/04 Season

$10^3 \times V$ (mm^3)	$10^2 \times A_{pred.}$ Linear Reg. Model (mm^2)	Non – Linear Reg. Model (mm^2)	$10^2 \times A_{act.}$ (mm^2)
910.00	442.46	436.52	446.70
853.00	425.98	416.87	430.30
959.00	456.62	457.09	422.90
923.00	446.21	446.68	519.50
1085.00	493.03	501.19	503.00
940.00	451.13	446.68	406.80
743.00	394.19	380.19	367.70
1291.00	552.57	562.34	559.20
1239.00	537.54	549.54	554.90
2288.00	840.70	831.76	832.80

* * For a linear regression model: $A = 17946.6 + 28.9V$
a non-linear regression Model according to Banks (1985): $A = 372.4V^{0.7}$

Appendix 12: Predicted Surface Areas ($A_{pred.}$) Using A Linear and A based on Watermelon Volume compared *Non-Linear Regression Models with Actual Surface Areas ($A_{act.}$) for 2004/05 Season

$10^3 \times V$ (mm^3)	$10^2 \times A_{pred.}$ Linear Reg. Model (mm^2)	Non – Linear Reg. Model (mm^2)	$10^2 \times A_{act.}$ (mm^2)
1218.00	563.25	549.54	496.40
1401.00	612.11	602.56	642.70
1310.00	587.81	575.44	854.20
1236.00	568.05	549.54	513.40
1271.00	577.40	562.34	594.50
1234.00	567.52	549.54	518.30
1304.00	586.21	575.44	537.50
1317.00	589.68	575.44	578.70
1370.00	603.83	602.56	499.60
1267.00	576.33	562.34	521.80
1474.00	631.60	630.96	630.50
1471.00	630.80	630.96	588.00
1478.00	632.67	645.65	623.50
1547.00	651.09	645.65	595.60
1267.00	576.33	562.34	473.80
1640.00	675.92	676.08	682.00
1260.00	574.46	562.34	613.00
1426.00	618.78	616.60	619.90
1548.00	651.36	645.65	671.90

* * For a linear regression model: $A = 23804.2 + 26.7V$
a non-linear regression Model according to Banks (1985): $A = 411.1V^{0.689}$

1467.00	629.73	645.65	650.00
1465.00	629.20	630.96	721.50
1461.00	628.13	616.60	638.90
1846.00	730.92	724.44	749.60
1565.00	655.90	660.69	649.10
1666.00	682.86	676.08	711.40
1852.00	732.53	741.31	712.60
1811.00	721.58	724.44	721.80
1553.00	652.69	645.65	643.50
1567.00	656.43	660.69	687.10
1666.00	682.86	676.08	647.80
1837.00	728.52	724.44	723.00
1868.00	736.80	741.31	733.60
1710.00	694.61	691.83	692.30
1556.00	653.49	645.65	664.90
1620.00	670.58	676.08	685.20
1946.00	757.62	758.58	759.00
1618.00	670.05	660.69	725.30
1766.00	709.56	707.95	733.50
2030.00	780.05	776.25	663.00
1845.00	730.66	724.44	754.30
1710.00	694.61	691.83	700.90
2010.00	774.71	776.25	789.50
1650.00	678.59	676.08	618.00
1790.00	715.97	724.44	750.30
1907.00	747.21	741.31	769.20
2018.00	776.85	776.25	763.20
2002.00	772.58	776.25	750.10
1819.00	723.72	724.44	694.80

1560.00	654.56	645.65	665.10
2242.00	836.66	831.76	849.20
1939.00	755.76	758.58	769.30
1632.00	673.79	676.08	734.00
1729.00	699.69	691.83	666.00
1670.00	683.93	676.08	727.40
1940.00	756.02	758.58	743.30
2015.00	776.05	776.25	698.00
1606.00	666.84	660.69	682.60
1603.00	666.04	660.69	715.50
1860.00	734.66	741.31	717.10
1802.00	719.18	724.44	758.80
2016.00	776.31	776.25	729.30
3118.00	1070.55	1047.13	1082.10
2810.00	988.31	977.24	966.70
2205.00	826.78	831.76	838.10
2360.00	868.16	870.96	859.80
2565.00	922.90	912.01	964.00
1771.00	710.90	707.95	748.90

Appendix 13: Oils and Fats: Production and Consumption Projections to the year 2010*

OILS	PRODUCTION				TOTAL CONSUMPTION				PER CAPITA	
	Base Period 1/	Projection 2010	Growth Rates 89-99	Growth Rates 99-2010	Base Period 1/	Projection 2010	Growth Rates 89-99	Growth Rates 99-2010	Base Period 1/	Projection 2010
	(...000 tonnes...)		(...% per year...)		(...000 tonnes...)		(...% per year...)		(...kg/person...)	
WORLD	**110 287**	**145 704**	**4.5**	**2.6**	**111 594**	**145 682**	**4.4**	**2.5**	**18.5**	**21.2**
DEVELOPING	**65 064**	**92 976**	**5.3**	**3.3**	**66 677**	**90 114**	**5.7**	**2.8**	**14.1**	**16.3**
AFRICA	5 031	5 866	3.0	1.4	8 188	11 189	3.9	2.9	10.4	11.1
NORTH AFRICA	566	669	2.6	1.5	2 834	3 699	3.8	2.5	20.1	21.9
Egypt	178	174	4.3	-0.2	1 348	1 817	4.7	2.7	20.1	22.7
Morocco	112	143	-1.3	2.2	557	679	6.2	1.8	20.0	20.7
SUB-SAHARA	4 465	5 198	3.0	1.4	5 354	7 490	3.9	3.1	8.3	9.0
Côte d'Ivoire	402	444	3.2	0.9	304	382	7.2	2.1	20.9	21.0
Nigeria	1 513	1 747	2.2	1.3	1 653	2 260	3.2	2.9	15.2	16.3
Ethiopia	115	143	5.9	2.0	136	212	3.3	4.2	1.1	1.3
LATIN AMER. & CARIB.	16 975	24 571	5.6	3.4	11 647	14 766	3.9	2.2	22.8	24.8
CENTRAL AMERICA	895	1 224	2.1	2.9	3 187	3 958	5.3	2.0	24.0	25.1
Mexico	467	732	-0.6	4.2	2 458	2 897	5.2	1.5	25.2	25.7
CARIBBEAN	73	76	-0.1	0.4	525	665	-0.7	2.2	14.9	16.9
Dominican Rep.	42	45	2.0	0.7	214	281	3.5	2.5	25.6	29.0
SOUTH AMERICA	16 007	23 271	5.9	3.5	7 935	10 144	3.8	2.3	23.1	25.5
Argentina	6 500	9 443	7.3	3.5	963	1 239	2.7	2.3	26.3	29.9
Brazil	6 928	10 534	5.1	3.9	4 210	5 504	3.9	2.5	25.1	28.8
Chile	205	222	-2.9	0.7	443	498	6.4	1.1	29.5	29.3
Uruguay	74	91	5.1	1.9	27	47	-2.5	5.1	8.2	13.1
ASIA	42 527	61 930	5.5	3.5	46 644	63 910	6.5	2.9	13.6	16.3
NEAR EAST	1 375	1 607	2.6	1.4	5 044	6 370	5.4	2.1	20.2	20.3
Iran Islamic Rep.	242	278	6.9	1.3	1 381	1 733	7.4	2.1	20.7	22.5
Saudi Arabia	3	3	-7.3	0.0	328	457	3.8	3.1	15.7	15.9
Turkey	792	904	0.6	1.2	1 819	2 196	3.9	1.7	27.7	28.9
SOUTH ASIA	9 360	12 209	4.6	2.4	15 810	21 652	6.8	2.9	12.0	13.9
India	8 200	10 750	4.5	2.5	12 157	16 238	7.4	2.7	12.2	14.1
Pakistan	918	1 193	6.9	2.4	2 492	3 808	4.6	3.9	16.4	19.1
SOUTH EAST ASIA	31 792	48 115	6.0	3.8	25 790	35 888	6.6	3.0	13.9	17.5
China, Mainland	10 156	13 602	5.6	2.7	14 249	21 006	6.9	3.6	11.4	15.6
Indonesia	7 577	14 235	9.6	5.9	3 659	5 412	5.8	3.6	17.5	22.7
Korea Rep	80	82	-0.7	0.3	847	849	3.2	0.0	18.2	17.0
Malaysia	11 176	16 869	5.5	3.8	2 676	3 325	5.9	2.0	122.6	128.3
Philippines	1 305	1 504	-0.1	1.3	592	783	3.4	2.6	7.9	8.6
Singapore			0.0	-12.8	569	628	0.0	0.9	161.6	161.6
Thailand	688	919	6.6	2.7	812	1 015	7.8	2.1	13.3	15.3
Viet Nam	244	273	7.2	1.0	393	635	14.3	4.5	5.0	7.0
OCEANIA	532	608	6.5	1.2	199	249	13.2	2.1	28.2	28.4
DEVELOPED	**38 749**	**44 456**	**4.3**	**1.3**	**38 600**	**47 187**	**3.9**	**1.8**	**43.4**	**51.1**
NORTH AMERICA	24 206	28 426	4.8	1.5	14 992	20 369	3.9	2.8	48.8	61.4
Canada	3 937	4 613	9.2	1.5	1 165	1 687	6.3	3.4	37.8	49.7
United States	20 269	23 813	4.1	1.5	13 826	18 682	3.8	2.8	50.1	62.7
WESTERN EUROPE	11 923	12 781	3.6	0.6	18 971	21 621	4.2	1.2	48.9	55.6
EU(15)	11 615	12 486	3.6	0.7	18 380	20 989	4.2	1.2	49.0	55.9
OCEANIA	1 832	2 442	9.5	2.6	548	728	-0.4	2.6	24.3	29.3
Australia	1 394	1 909	9.0	2.9	440	578	-1.1	2.5	23.5	28.0
New Zealand	438	532	11.3	1.8	108	150	2.9	3.0	28.2	35.6
OTHER DEVELOPED	788	808	-3.5	0.2	4 090	4 469	2.9	0.8	23.7	25.2
Japan	362	315	-7.0	-1.3	3 067	3 248	2.5	0.5	24.2	25.5
South Africa	402	464	1.1	1.3	824	948	3.8	1.3	20.6	22.3
TRANSITIONAL	**6 474**	**8 271**	**-1.0**	**2.3**	**6 317**	**8 381**	**-1.9**	**2.6**	**15.3**	**20.2**
EASTERN EUROPE	2 906	3 477	0.9	1.6	2 732	3 458	0.9	2.2	22.5	28.7
Hungary	518	620	-0.5	1.7	318	464	0.7	3.5	31.6	48.2
Poland	689	829	-0.6	1.7	904	1 192	4.2	2.5	23.3	30.4
Czech Rep.	361	393	0.0	0.8	296	331	0.0	1.0	28.8	32.9
CIS	3 473	4 688	0.0	2.8	3 423	4 763	0.0	3.0	12.1	16.6
Kazakhstan	66	69	0.0	0.5	128	154	0.0	1.7	7.9	9.4
Russian Fed.	1 685	2 489	0.0	3.6	2 023	2 832	0.0	3.1	13.7	19.6
Ukraine	1 109	1 467	0.0	2.6	525	800	0.0	3.9	10.4	16.4
BALTIC	94	107	0.0	1.1	161	160	0.0	-0.1	21.6	22.9

* FAO Commodities and Trade Technical Paper, 2003.

[*] **Appendix 14:** Oils and Fats: Trade Projections to the year 2010

OILS	IMPORTS Base Period [1/]	IMPORTS Projection 2010	IMPORTS Growth Rates 89-99		EXPORTS Base Period [1/]	EXPORTS Projection 2010	EXPORTS Growth Rates 89-99		IMPORT SHARE Base Period [1/]	IMPORT SHARE Projection 2010	EXPORT SHARE Base Period [1/]	EXPORT SHARE Projection 2010
	(...000 tonnes...)		(...% per year...)		(...000 tonnes...)		(...% per year...)		(......%......)		(......%......)	
WORLD	**47 255**	**60 305**	**6.9**	**2.2**	**44 735**	**60 343**	**6.8**	**2.8**	**100.0**	**100.0**	**100.0**	**100.0**
DEVELOPING	**28 829**	**39 230**	**8.5**	**2.8**	**26 685**	**42 158**	**7.4**	**4.2**	**61.0**	**65.1**	**59.7**	**69.9**
AFRICA	3 883	6 033	5.1	4.1	765	704	3.9	-0.8	8.2	10.0	1.7	1.2
NORTH AFRICA	2 398	3 207	4.3	2.7	170	172	9.9	0.1	5.1	5.3	0.4	0.3
Egypt	1 185	1 656	4.9	3.1	12	11	18.5	0.0	2.5	2.7	0.0	0.0
Morocco	453	550	9.1	1.8	14	14	0.6	0.1	1.0	0.9	0.0	0.0
SUB-SAHARA	1 484	2 826	6.5	6.0	595	532	2.8	-1.0	3.1	4.7	1.3	0.9
Côte d'Ivoire	25	27	12.6	0.7	122	89	-1.9	-2.9	0.1	0.0	0.3	0.1
Nigeria	184	559	26.7	10.6	45	44	4.4	-0.1	0.4	0.9	0.1	0.1
Ethiopia	44	92	2.1	7.0	23	22	27.4	-0.1	0.1	0.2	0.1	0.0
LATIN AMER. & CARIB.	5 010	5 758	7.1	1.3	10 074	15 540	8.7	4.0	10.6	9.5	22.5	25.8
CENTRAL AMERICA	2 592	2 961	7.7	1.2	239	220	15.4	-0.8	5.5	4.9	0.5	0.4
Mexico	2 130	2 251	7.8	0.5	79	78	13.6	0.0	4.5	3.7	0.2	0.1
CARIBBEAN	452	589	-0.9	2.4			-37.0	0.0	1.0	1.0	0.0	0.0
Dominican Rep.	172	236	3.5	2.9			0.0	0.0	0.4	0.4	0.0	0.0
SOUTH AMERICA	1 966	2 208	9.6	1.1	9 834	15 320	8.6	4.1	4.2	3.7	22.0	25.4
Argentina	157	171	45.5	0.8	5 532	8 366	8.3	3.8	0.3	0.3	12.4	13.9
Brazil	482	527	12.3	0.8	3 155	5 553	7.8	5.3	1.0	0.9	7.1	9.2
Chile	251	311	14.4	2.0	34	34	-10.5	0.0	0.5	0.5	0.1	0.1
Uruguay	22	27	7.2	1.6	69	71	12.4	0.2	0.0	0.0	0.2	0.1
ASIA	19 893	27 391	9.7	3.0	15 470	25 507	6.9	4.7	42.1	45.4	34.6	42.3
NEAR EAST	3 888	5 002	6.7	2.3	240	239	7.2	0.0	8.2	8.3	0.5	0.4
Iran Islamic Rep.	1 180	1 496	7.9	2.2	41	40	0.0	-0.1	2.5	2.5	0.1	0.1
Saudi Arabia	327	456	4.1	3.1	3	3	0.0	0.0	0.7	0.8	0.0	0.0
Turkey	1 174	1 459	6.7	2.0	168	168	3.7	0.0	2.5	2.4	0.4	0.3
SOUTH ASIA	6 981	9 881	12.1	3.2	423	422	29.2	0.0	14.8	16.4	0.9	0.7
India	4 378	5 903	20.6	2.8	402	402	48.8	0.0	9.3	9.8	0.9	0.7
Pakistan	1 672	2 626	4.0	4.2	9	9	37.6	0.0	3.5	4.4	0.0	0.0
SOUTH EAST ASIA	9 024	12 508	9.7	3.0	14 808	24 846	6.6	4.8	19.1	20.7	33.1	41.2
China, Mainland	4 799	7 776	11.2	4.5	489	492	6.8	0.1	10.2	12.9	1.1	0.8
Indonesia	113	128	-10.1	1.2	4 142	8 951	12.6	7.3	0.2	0.2	9.3	14.8
Korea Rep.	775	775	3.9	0.0	8	8	36.5	0.0	1.6	1.3	0.0	0.0
Malaysia	680	731	9.9	0.7	9 016	14 271	5.4	4.3	1.4	1.2	20.2	23.6
Philippines	193	212	16.9	0.8	957	930	0.2	-0.3	0.4	0.4	2.1	1.5
Singapore	569	628	0.0	0.9			0.0	0.1	1.2	1.0	0.0	0.0
Thailand	226	200	25.8	-1.1	103	103	40.5	0.1	0.5	0.3	0.2	0.2
Viet Nam	196	409	61.9	6.9	47	47	9.4	-0.1	0.4	0.7	0.1	0.1
OCEANIA	43	49	7.5	1.2	376	408	4.3	0.7	0.1	0.1	0.8	0.7
DEVELOPED	16 274	18 568	4.9	1.2	15 770	15 788	5.6	0.0	34.4	30.8	35.3	26.2
NORTH AMERICA	2 560	2 841	5.8	0.9	11 256	10 830	5.7	-0.4	5.4	4.7	25.2	17.9
Canada	505	571	11.4	1.1	3 037	3 502	10.0	1.3	1.1	0.9	6.8	5.8
United States	2 055	2 270	4.7	0.9	8 219	7 329	4.5	-1.0	4.3	3.8	18.4	12.1
WESTERN EUROPE	10 072	11 668	5.1	1.3	2 857	2 844	3.7	0.0	21.3	19.3	6.4	4.7
EU(15)	9 605	11 158	5.1	1.4	2 673	2 671	3.7	0.0	20.3	18.5	6.0	4.4
OCEANIA	264	290	2.0	0.9	1 548	2 004	14.9	2.4	0.6	0.5	3.5	3.3
Australia	200	219	1.5	0.8	1 154	1 550	15.6	2.7	0.4	0.4	2.6	2.6
New Zealand	64	71	3.4	1.0	394	454	13.1	1.3	0.1	0.1	0.9	0.8
OTHER DEVELOPED	3 377	3 769	4.0	1.0	109	109	-10.5	0.0	7.1	6.3	0.2	0.2
Japan	2 684	2 944	3.4	0.8	12	12	-26.6	0.0	5.7	4.9	0.0	0.0
South Africa	513	576	6.8	1.1	91	91	4.8	0.0	1.1	1.0	0.2	0.2
TRANSITIONAL	**2 153**	**2 507**	**3.5**	**1.4**	**2 281**	**2 397**	**8.8**	**0.5**	**4.6**	**4.2**	**5.1**	**4.0**
EASTERN EUROPE	839	1 027	4.6	1.9	1 021	1 046	4.2	0.2	1.8	1.7	2.3	1.7
Hungary	96	109	11.1	1.1	306	264	0.8	-1.3	0.2	0.2	0.7	0.4
Poland	337	482	9.6	3.3	119	119	-7.6	0.0	0.7	0.8	0.3	0.2
Czech Rep.	111	116	0.0	0.3	177	178	0.0	0.1	0.2	0.2	0.4	0.3
CIS	1 181	1 361	0.0	1.3	1 194	1 286	0.0	0.7	2.5	2.3	2.7	2.1
Kazakhstan	65	89	0.0	2.8	4	4	0.0	-0.1	0.1	0.1	0.0	0.0
Russian Fed.	835	810	0.0	-0.3	471	467	0.0	-0.1	1.8	1.3	1.1	0.8
Ukraine	50	57	0.0	1.3	623	723	0.0	1.4	0.1	0.1	1.4	1.2
BALTIC	133	118	0.0	-1.0	66	65	0.0	-0.1	0.3	0.2	0.1	0.1

[*] FAO Commodities and Trade Technical Paper, 2003.

Appendix 15: Oil Meals: Production and Consumption Projections to the year 2010[*]

MEALS	PRODUCTION				TOTAL CONSUMPTION				PER CAPITA	
	Base Period [1/]	Projection 2010	Growth Rates 89-99	Growth Rates 99-2010	Base Period [1/]	Projection 2010	Growth Rates 89-99	Growth Rates 99-2010	Base Period [1/]	Projection 2010
	(...000 tonnes...)		(...% per year...)		(...000 tonnes...)		(...% per year...)		(...kg/person...)	
WORLD	**78 596**	**101 374**	**4.0**	**2.3**	**78 113**	**100 854**	**3.5**	**2.4**	**12.9**	**14.7**
DEVELOPING	**41 896**	**58 978**	**4.5**	**3.2**	**35 682**	**49 583**	**6.7**	**3.0**	**7.5**	**9.0**
AFRICA	1 568	1 844	2.7	1.5	2 177	3 123	4.3	3.3	2.8	3.1
NORTH AFRICA	181	199	-1.7	0.9	1 016	1 542	3.8	3.9	7.2	9.1
Egypt	111	102	-1.5	-0.7	546	849	7.5	4.1	8.1	10.6
Morocco	48	71	-2.9	3.6	164	242	9.5	3.6	5.9	7.4
SUB-SAHARA	1 387	1 644	3.5	1.6	1 161	1 581	4.6	2.8	1.8	1.9
Côte d'Ivoire	59	64	4.9	0.6	35	45	7.7	2.3	2.4	2.5
Nigeria	298	368	4.3	1.9	253	341	4.2	2.7	2.3	2.5
Ethiopia	53	67	1.1	2.1	52	82	1.7	4.3	0.4	0.5
LATIN AMER. & CARIB.	23 194	35 555	5.5	4.0	8 217	11 436	5.1	3.1	16.1	19.2
CENTRAL AMERICA	251	370	-5.3	3.6	2 225	3 014	6.8	2.8	16.8	19.1
Mexico	209	324	-5.6	4.1	1 889	2 545	6.5	2.7	19.4	22.5
CARIBBEAN	5	5	-15.8	-1.0	317	415	-0.2	2.5	9.0	10.6
Dominican Rep.	2	2	-15.2	-0.2	138	185	5.9	2.7	16.5	19.0
SOUTH AMERICA	22 937	35 181	5.7	4.0	5 675	8 006	4.9	3.2	16.5	20.1
Argentina	8 541	13 815	8.1	4.5	513	694	0.1	2.8	14.0	16.7
Brazil	11 220	17 019	5.0	3.9	3 402	4 909	5.6	3.4	20.3	25.7
Chile	550	910	-3.6	4.7	369	475	11.0	2.3	24.6	27.9
Uruguay	23	29	-1.2	2.2	28	40	9.2	3.3	8.5	11.3
ASIA	17 106	21 551	3.6	2.1	25 269	34 987	7.5	3.0	7.4	8.9
NEAR EAST	692	813	0.7	1.5	2 296	3 291	6.7	3.3	9.2	10.5
Iran Islamic Rep.	111	139	2.0	2.1	479	655	6.4	2.9	7.2	8.5
Saudi Arabia	4	4	3.4	0.0	266	437	7.4	4.6	12.7	15.2
Turkey	420	483	-1.1	1.3	904	1 250	5.9	3.0	13.8	16.4
SOUTH ASIA	6 870	8 742	3.4	2.2	5 704	7 435	3.8	2.4	4.3	4.8
India	6 046	7 781	3.5	2.3	4 701	6 029	3.6	2.3	4.7	5.2
Pakistan	681	808	3.4	1.6	779	1 064	4.7	2.9	5.1	5.3
SOUTH EAST ASIA	9 545	11 996	3.9	2.1	17 269	24 261	9.2	3.1	9.3	11.8
China Mainland	7 650	9 665	4.7	2.1	10 821	15 049	12.3	3.0	8.7	11.2
Korea Rep.	111	111	-4.8	0.0	1 440	1 903	5.2	2.6	31.0	38.1
Laos	9	12	3.4	2.1	8	12	2.3	3.4	1.6	1.7
Malaysia	381	555	4.4	3.5	550	744	5.3	2.8	25.2	28.7
Philippines	145	167	-1.2	1.3	659	1 050	6.3	4.3	8.9	11.6
Singapore			0.0	0.0	27	69	0.0	8.9	7.6	17.7
Thailand	406	411	0.7	0.1	1 368	1 871	9.0	2.9	22.5	28.1
Viet Nam	108	121	12.3	1.0	206	454	21.3	7.5	2.6	5.0
OCEANIA	28	28	4.1	0.1	19	38	8.4	6.7	2.7	4.3
DEVELOPED	**34 152**	**39 300**	**4.1**	**1.3**	**39 172**	**46 860**	**2.8**	**1.6**	**44.0**	**50.8**
NORTH AMERICA	28 775	33 565	4.9	1.4	15 827	19 478	4.1	1.9	51.5	58.7
Canada	2 035	2 300	7.7	1.1	995	1 460	2.1	3.5	32.3	43.0
United States	26 740	31 265	4.7	1.4	14 831	18 018	4.3	1.8	53.7	60.5
WESTERN EUROPE	4 081	4 259	1.6	0.4	19 040	22 467	2.0	1.5	49.1	57.7
EU(15)	3 761	3 951	1.5	0.4	18 607	22 007	2.0	1.5	49.6	58.6
OCEANIA	548	778	11.9	3.2	273	406	3.6	3.7	12.1	16.4
Australia	527	747	11.6	3.2	236	356	2.3	3.8	12.6	17.3
New Zealand	21	30	27.6	3.7	37	50	22.3	2.6	9.7	11.8
OTHER	748	697	-5.1	-0.6	4 033	4 509	1.5	1.0	23.4	25.5
Japan	436	347	-7.5	-2.1	3 232	3 453	0.9	0.6	25.5	27.1
South Africa	296	334	0.0	1.1	522	652	3.8	2.0	13.1	15.3
TRANSITIONAL	**2 549**	**3 096**	**-2.8**	**1.8**	**3 259**	**4 411**	**-7.0**	**2.8**	**7.9**	**10.6**
EASTERN EUROPE	1 000	1 150	0.1	1.3	1 844	2 503	-3.4	2.8	15.2	20.8
Hungary	151	169	-0.8	1.0	332	442	-4.4	2.6	33.0	45.9
Poland	199	216	-3.2	0.7	535	705	-2.1	2.5	13.8	18.0
Czech Rep.	136	146	0.0	0.6	247	298	0.0	1.7	24.1	29.6
CIS	1 527	1 919	0.0	2.1	1 343	1 824	0.0	2.8	4.7	6.4
Kazakhstan	39	37	0.0	-0.4	40	52	0.0	2.4	2.5	3.1
Russian Fed.	645	887	0.0	2.9	641	823	0.0	2.3	4.4	5.7
Ukraine	335	441	0.0	2.5	97	246	0.0	8.8	1.9	5.1
BALTIC	21	26	0.0	1.9	72	84	0.0	1.4	9.6	12.0

[*] FAO Commodities and Trade Technical Paper, 2003.

*Appendix 16: Oil meals: Trade Projections to the year 2010

MEALS	IMPORTS				EXPORTS				IMPORT SHARE		EXPORT SHARE	
	Base Period 1/	Projection 2010	Growth Rates 89-99		Base Period 1/	Projection 2010	Growth Rates 89-99		Base Period 1/	Projection 2010	Base Period 1/	Projection 2010
	(...000 tonnes...)		(...% per year...)		(...000 tonnes...)		(...% per year...)		(......%......)		(......%......)	
WORLD	**38 409**	**50 233**	**4.5**	**2.5**	**37 874**	**50 281**	**5.3**	**2.6**	**100.0**	**100.0**	**100.0**	**100.0**
DEVELOPING	**15 946**	**23 238**	**11.2**	**3.5**	**21 801**	**32 389**	**4.8**	**3.7**	**41.5**	**46.3**	**57.6**	**64.4**
AFRICA	933	1 581	6.0	4.9	324	302	1.2	-0.7	2.4	3.1	0.9	0.6
NORTH AFRICA	847	1 355	5.7	4.4	12	12	9.9	0.0	2.2	2.7	0.0	0.0
Egypt	439	750	12.3	5.0	4	3	3.7	-0.1	1.1	1.5	0.0	0.0
Morocco	124	180	40.1	3.4	8	8	12.9	0.0	0.3	0.4	0.0	0.0
SUB-SAHARA	86	226	9.1	9.2	312	290	1.0	-0.7	0.2	0.4	0.8	0.6
Côte d'Ivoire	2	3	1.5	0.7	27	21	1.9	-2.2	0.0	0.0	0.1	0.0
Nigeria	5	6	5.1	0.8	50	33	5.0	-3.8	0.0	0.0	0.1	0.1
Ethiopia		16	0.0	0.0	1		-9.8	0.0	0.0	0.0	0.0	0.0
LATIN AMER. & CARIB.	4 127	5 250	10.6	2.2	18 905	29 234	6.5	4.0	10.7	10.5	49.9	58.1
CENTRAL AMERICA	2 044	2 668	10.8	2.5	23	23	4.0	-0.1	5.3	5.3	0.1	0.0
Mexico	1 733	2 228	10.6	2.3	6	6	32.1	-0.1	4.5	4.4	0.0	0.0
CARIBBEAN	312	410	0.6	2.5			0.0	0.0	0.8	0.8	0.0	0.0
Dominican Rep.	136	183	7.0	2.7			0.0	0.0	0.4	0.4	0.0	0.0
SOUTH AMERICA	1 771	2 172	13.8	1.9	18 882	29 211	6.5	4.0	4.6	4.3	49.9	58.1
Argentina	213	233	-101.1	0.8	8 148	13 290	9.1	4.5	0.6	0.5	21.5	26.4
Brazil	291	325	25.9	1.0	8 047	12 382	5.0	4.0	0.8	0.6	21.2	24.6
Chile	215	232	21.1	0.7	382	660	-5.8	5.1	0.6	0.5	1.0	1.3
Uruguay	24	30	24.5	2.1	18	18	0.9	0.1	0.1	0.1	0.0	0.0
ASIA	10 880	16 391	12.0	3.8	2 556	2 848	-2.4	1.0	28.3	32.6	6.7	5.7
NEAR EAST	1 642	2 507	11.3	3.9	28	28	10.5	-0.1	4.3	5.0	0.1	0.1
Iran Islamic Rep.	369	517	8.3	3.1	1	1	0.0	-0.2	1.0	1.0	0.0	0.0
Saudi Arabia	262	433	7.5	4.7			0.0	-0.1	0.7	0.9	0.0	0.0
Turkey	503	778	25.2	4.0	10	10	-0.3	-0.1	1.3	1.5	0.0	0.0
SOUTH ASIA	214	475	20.2	7.5	1 500	1 778	3.9	1.6	0.6	0.9	4.0	3.5
India	27	29	13.2	0.7	1 488	1 777	4.0	1.6	0.1	0.1	3.9	3.5
Pakistan	95	257	42.1	9.5			-9.4	-0.1	0.2	0.5	0.0	0.0
SOUTH EAST ASIA	9 024	13 409	12.1	3.7	1 027	1 042	-7.4	0.1	23.5	26.7	2.7	2.1
China Mainland	3 847	5 804	30.6	3.8	336	333	-15.0	-0.1	10.0	11.6	0.9	0.7
Korea Rep.	1 348	1 811	7.0	2.7	19	19	19.5	-0.1	3.5	3.6	0.0	0.0
Laos			0.0	31.7	1		0.0	0.0	0.0	0.0	0.0	0.0
Malaysia	467	482	5.3	0.3	296	293	4.2	-0.1	1.2	1.0	0.8	0.6
Philippines	584	983	6.3	4.8	94	94	-2.8	0.0	1.5	2.0	0.2	0.2
Singapore	27	69	0.0	8.9			0.0	0.0	0.1	0.1	0.0	0.0
Thailand	974	1 473	15.2	3.8	13	13	-10.0	0.1	2.5	2.9	0.0	0.0
Viet Nam	139	374	0.0	9.4	42	41	25.9	-0.2	0.4	0.7	0.1	0.1
OCEANIA	6	16	9.7	8.6	15	6	2.0	-8.8	0.0	0.0	0.0	0.0
DEVELOPED	**20 723**	**24 646**	**2.9**	**1.6**	**15 046**	**16 859**	**5.7**	**1.0**	**54.0**	**49.1**	**39.7**	**33.5**
NORTH AMERICA	1 125	1 227	6.8	0.8	13 441	15 117	5.4	1.1	2.9	2.4	35.5	30.1
Canada	553	620	4.0	1.1	1 473	1 457	10.7	-0.1	1.4	1.2	3.9	2.9
United States	572	607	10.5	0.5	11 968	13 660	4.9	1.2	1.5	1.2	31.6	27.2
WESTERN EUROPE	16 120	19 396	2.5	1.7	1 137	1 160	8.4	0.2	42.0	38.6	3.0	2.3
EU(15)	15 762	18 974	2.5	1.7	892	890	9.0	0.0	41.0	37.8	2.4	1.8
OCEANIA	147	164	12.8	1.0	422	536	30.3	2.2	0.4	0.3	1.1	1.1
Australia	111	126	10.9	1.1	403	517	30.3	2.3	0.3	0.3	1.1	1.0
New Zealand	35	38	23.0	0.6	19	19	30.7	0.0	0.1	0.1	0.0	0.0
OTHER	3 331	3 859	3.3	1.3	46	46	-13.8	0.0	8.7	7.7	0.1	0.1
Japan	2 804	3 114	2.8	1.0	8	6	-24.0	0.0	7.3	6.2	0.0	0.0
South Africa	260	353	6.6	2.8	35	35	-7.2	0.0	0.7	0.7	0.1	0.1
TRANSITIONAL	**1 740**	**2 350**	**-7.0**	**2.8**	**1 027**	**1 033**	**15.1**	**0.0**	**4.5**	**4.7**	**2.7**	**2.1**
EASTERN EUROPE	1 331	1 835	-3.1	3.0	499	480	9.0	-0.3	3.5	3.7	1.3	1.0
Hungary	244	348	-4.4	3.3	74	73	11.9	-0.1	0.6	0.7	0.2	0.1
Poland	440	593	-1.6	2.8	104	103	-2.4	-0.1	1.1	1.2	0.3	0.2
Czech Rep.	222	261	0.0	1.5	110	109	0.0	-0.1	0.6	0.5	0.3	0.2
CIS	341	440	0.0	2.3	511	536	0.0	0.4	0.9	0.9	1.3	1.1
Kazakhstan	3	17	0.0	15.6	2	2	0.0	-0.2	0.0	0.0	0.0	0.0
Russian Fed.	211	205	0.0	-0.3	204	269	0.0	2.6	0.5	0.4	0.5	0.5
Ukraine	30	40	0.0	2.6	265	235	0.0	-1.1	0.1	0.1	0.7	0.5
BALTIC	68	74	0.0	0.9	17	17	0.0	-0.2	0.2	0.1	0.0	0.0

* FAO Commodities and Trade Technical Paper, 2003.